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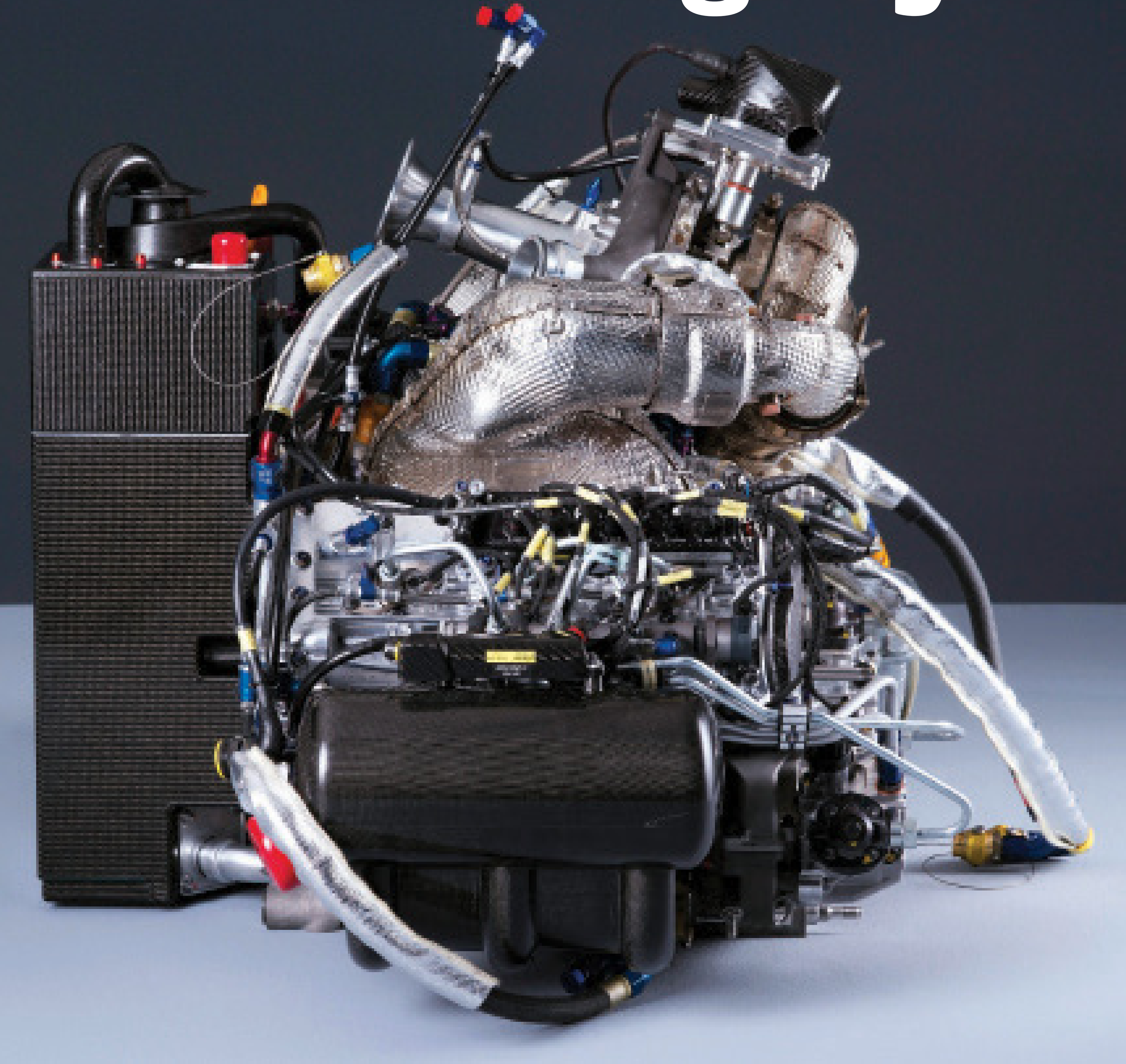

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If ever there was a more important time in the automotive world for engine development, I cannot think of it. With European targets for production cars focussing on reduced emissions, the trend in production cars is for small capacity engines, supported by hybrid systems.

Motor racing is playing its part, introducing new regulations in both Formula 1 and endurance racing that encourage efficiency and the development of hybrid systems. It is a major step, as the focus will switch from outright performance to reliability of complex systems. What is learned in racing will be transferable into production cars, which is why Mercedes, Ferrari, Renault and Honda have committed to racing programmes in Formula 1, and Porsche, Toyota and Audi are contesting the World Endurance Championship, including the Le Mans 24 hours.

At Racecar Engineering, we have been keeping up to date with the latest engine regulations and have featured some of the new 2014 drivetrains. In these pages, you will find a mix of features, from the latest Renault Formula 1 engine that was launched in Paris in June, to an historic piece on Ford's 1965 unit that was eventually was successful at the Indianapolis 500.

We have also included a feature on the development of Audi's V6 Le Mans engine, which details the extraordinary pace of development that racing commands to be successful in top flight motorsport, and shows how racing can improve the brand.

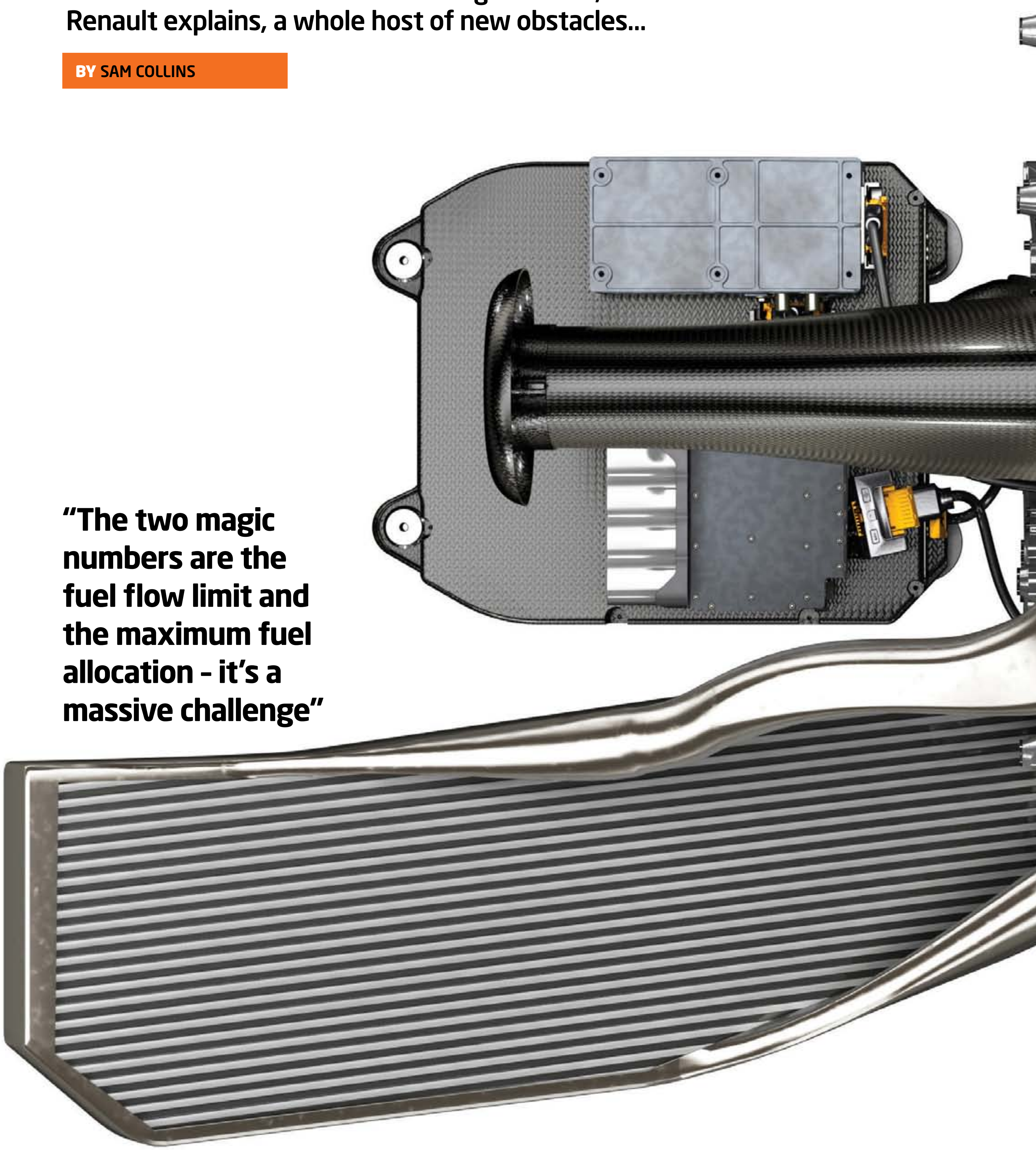
We look at the Mazda SkyActiv diesel racing engine that debuted at the Daytona 24 hours, and at the IndyCar engines that are also changing to meet with the demands of the consumer. This really is an exciting time in the development process for racing and production engines.

Andrew Cotton, editor

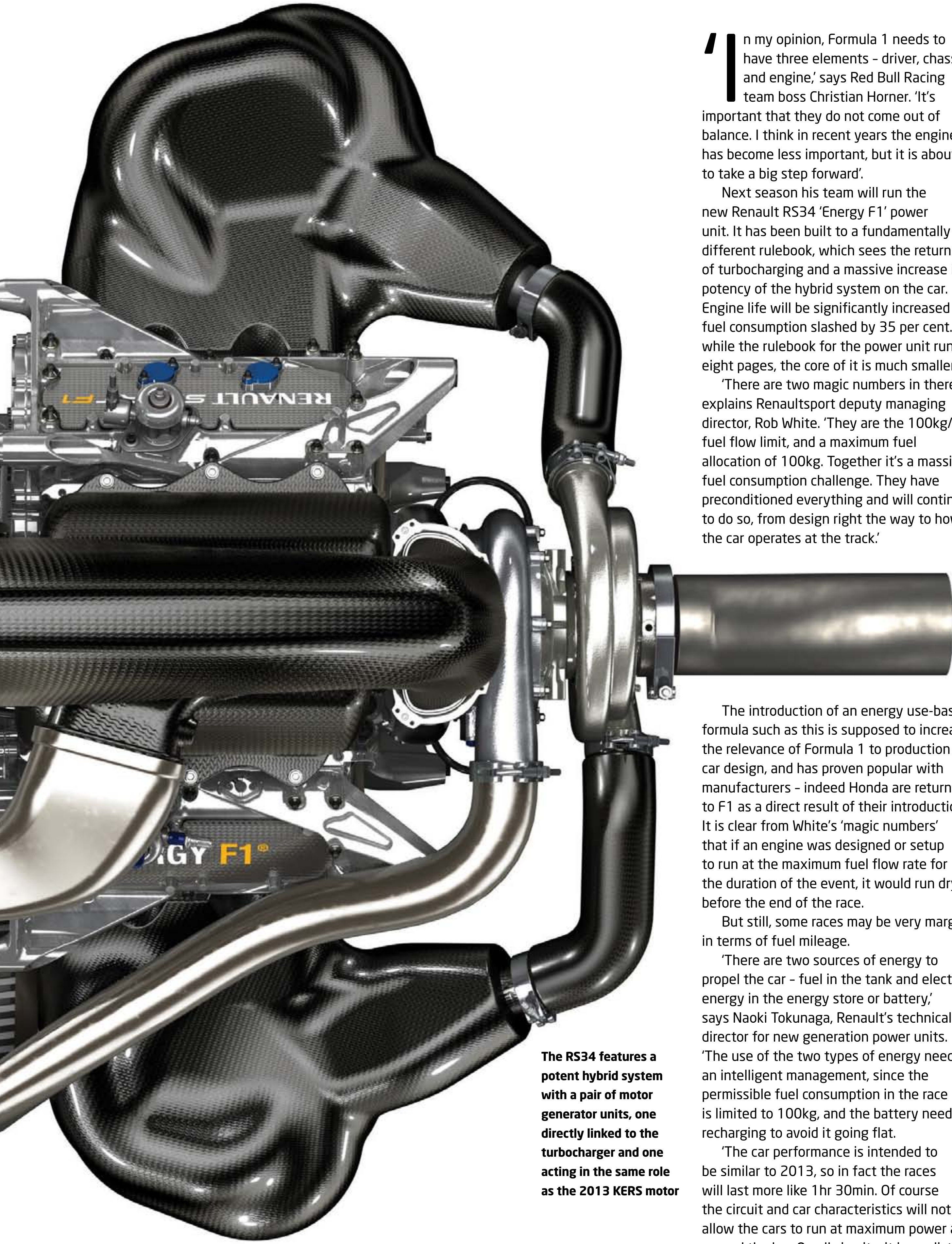
The third element

2014 will see a new breed of F1 engines. And, as Renault explains, a whole host of new obstacles…

BY SAM COLLINS



"The two magic numbers are the fuel flow limit and the maximum fuel allocation - it's a massive challenge"



The RS34 features a potent hybrid system with a pair of motor generator units, one directly linked to the turbocharger and one acting in the same role as the 2013 KERS motor

'In my opinion, Formula 1 needs to have three elements – driver, chassis and engine,' says Red Bull Racing team boss Christian Horner. 'It's important that they do not come out of balance. I think in recent years the engine has become less important, but it is about to take a big step forward'.

Next season his team will run the new Renault RS34 'Energy F1' power unit. It has been built to a fundamentally different rulebook, which sees the return of turbocharging and a massive increase in potency of the hybrid system on the car. Engine life will be significantly increased and fuel consumption slashed by 35 per cent. But while the rulebook for the power unit runs to eight pages, the core of it is much smaller.

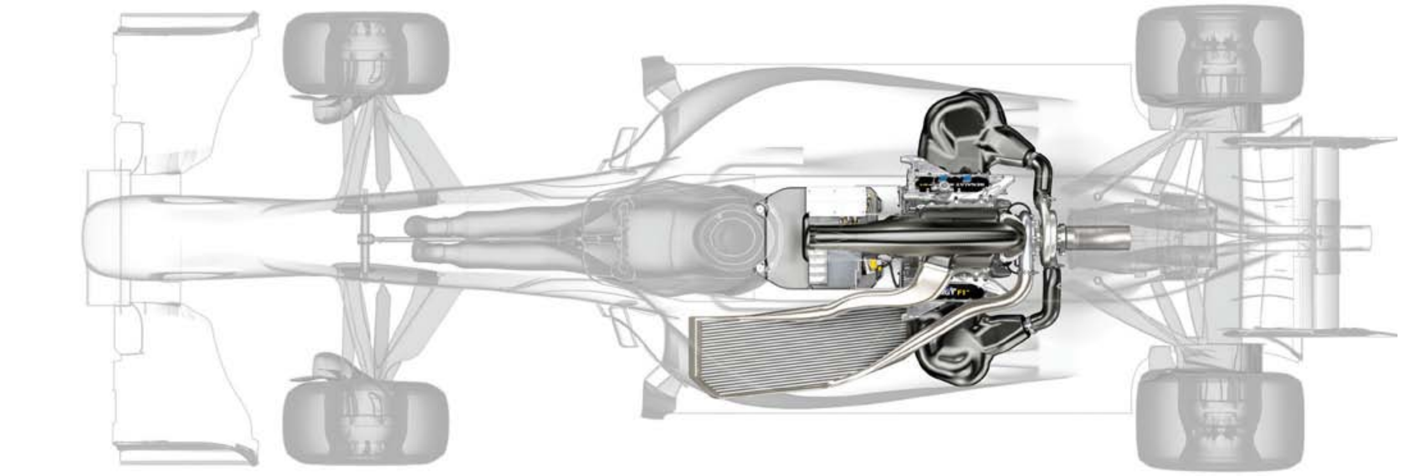
'There are two magic numbers in there,' explains Renaultsport deputy managing director, Rob White. 'They are the 100kg/h fuel flow limit, and a maximum fuel allocation of 100kg. Together it's a massive fuel consumption challenge. They have preconditioned everything and will continue to do so, from design right the way to how the car operates at the track.'

The introduction of an energy use-based formula such as this is supposed to increase the relevance of Formula 1 to production car design, and has proven popular with manufacturers – indeed Honda are returning to F1 as a direct result of their introduction. It is clear from White's 'magic numbers' that if an engine was designed or setup to run at the maximum fuel flow rate for the duration of the event, it would run dry before the end of the race.

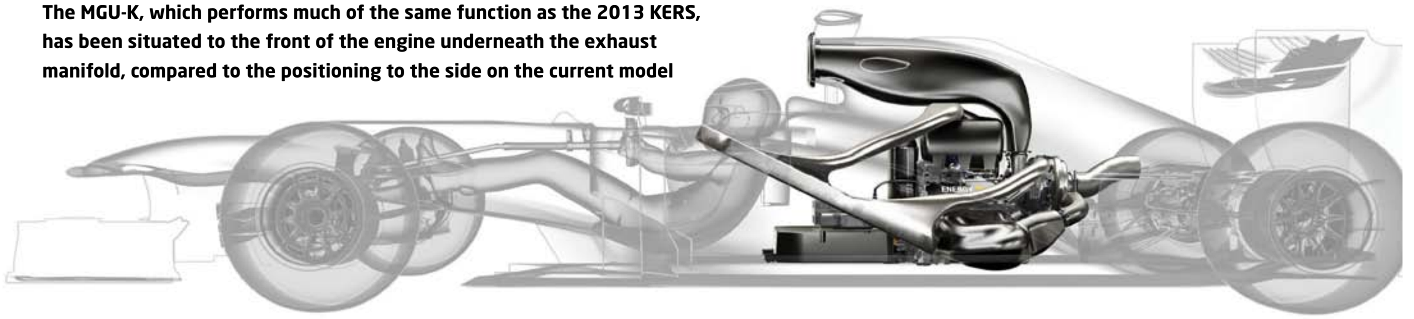
But still, some races may be very marginal in terms of fuel mileage.

'There are two sources of energy to propel the car – fuel in the tank and electrical energy in the energy store or battery,' says Naoki Tokunaga, Renault's technical director for new generation power units. 'The use of the two types of energy needs an intelligent management, since the permissible fuel consumption in the race is limited to 100kg, and the battery needs recharging to avoid it going flat.

'The car performance is intended to be similar to 2013, so in fact the races will last more like 1hr 30min. Of course the circuit and car characteristics will not allow the cars to run at maximum power all around the lap. On all circuits, it is predicted that the natural fuel consumption for the race distance will be close to the allowed 100kg, in some case just under, in some



The MGU-K, which performs much of the same function as the 2013 KERS, has been situated to the front of the engine underneath the exhaust manifold, compared to the positioning to the side on the current model



cases just over. If just over, then it will be necessary to decide how to use the available fuel.'

Of note is the fastest race of the season, the Italian Grand Prix at Monza, where the cars are at full throttle for 70 per cent of the lap. In 2012, the race distance was completed in 79 minutes which would, in theory, give a maximum average fuel flow of just under 76kg/h.

But at Monaco, the slowest course of the year, the race can take much longer due to having a far lower average speed. There, based on the 2012 event, the maximum average fuel flow rate is down to 56.6kg/h.

Singapore, one of the longest races of the year which often lasts two hours, has been highlighted by some as the most marginal race in terms of fuel mileage. There, based on a two hour long race, the maximum average flow rate will be 50kg/h.

In 2012 that race was time-limited rather than distance-limited due to safety car periods. The flow rate is calculated by time rather than distance, so in these scenarios teams could have to adapt their fuel use strategies in real-time. Indeed, if a safety car is deployed or weather conditions alter, the energy use strategy will also have to change.

'Everything we do to decrease the fuel consumption increases the power because of the flow limit,' White adds. 'Because of this we are all trying to make the power at the lowest possible RPM.'

This will have a significant impact on the aerodynamic design, meaning that teams will have to rethink how the car generates downforce. Notably this will fall due to the effective ban on blown diffusers, the single exhaust exit location being tightly controlled.

'There are lots of things that cause you to burn fuel and lots of things that give you lap time,' explains former Lotus technical director James Allison. 'When you design the cars for any year, you are trying to find the optimum combination of all of those things to make the fastest race time coupled with the best qualifying lap. It is certainly the case that you will have a different response next year to this year in terms of how dirty (in terms of drag) a downforce device you can use. But that does not mean that you will see the cars just scissoring downforce off it compared to what you are used to.

'There will certainly be opportunities. I suspect things like the front wing and the diffuser will follow similar paths to recent years, and the hunting ground will be how you cope with the low nose chassis and how you integrate what is a very fierce cooling requirement into the chassis without haemorrhaging downforce.'

Qualifying should be very interesting. With no regulation on fuel load, teams can exceed the maximum average flow rate, which would in theory give the engines more power. Indeed, in qualifying trim the power units should be more powerful than the current V8 engines. Teams could also run a driver-selectable map for overtaking or quick laps to make up time during a pit stop phase.

A further complexity is that the maximum fuel flow cannot be used below 10,000rpm.

'The maximum power of the engine will be at around 10,500rpm, and above that the power curve will be relatively flat,' says White. 'But they wanted them to run faster, which is perceived as a good thing to improve the show. It's about putting boundaries on the absurdity of the law of diminishing returns and stop an arms race to get to places that are extremely unusual. It's also about managing the risk. For a given power, the torque goes up inversely with the speed of the engine, so you would have very different transmissions. I hate to say it too, but it's important to everybody that these things sound good. I think these will, but if there had been no such rule then we would have run at very, very low engine speeds.'

Of course the RS34 Energy F1 is more than just a small capacity V6 engine. It features a hybrid system far more potent than anything seen in grand prix racing before. There's a pair of motor generator units, one linked directly to the turbocharger (MGU-H) and the other acting in the same role as the current KERS motor (MGU-K).

'The F1 cars for 2014 may be categorised as a hybrid electric vehicle (HEV), which combines a conventional internal combustion engine with an electric propulsion system,

"Everything we do to decrease the fuel consumption increases the power because of the flow limit"

Despite only having a 1.6-litre combustion engine at its heart, the new power units are noticeably larger than the current 2.4-litre V8s, due to all the additional subsystems

rather than a full electric vehicle (EV),' explains Tokunaga. 'Like road-going HEVs, the battery in the F1 cars is relatively small sized. The relevant technical regulations mean that if the battery discharged the maximum permitted energy around the lap, the battery would go flat just after a couple of laps. In order to maintain "state of charge" of the battery, electrical energy management will be just as important as fuel management.

'The energy management system ostensibly decides when and how much fuel to take out of the tank, and when and how much energy to take out or put back into the battery. The overall objective is to minimise the time going round a lap of the circuit for a given energy budget. This might sound anything but road-relevant, but – essentially – this is the same problem as the road cars: minimising fuel consumption for a given travel in a given time. The input and output are just the other way around. The question then becomes where to deploy the energy in the lap. This season, KERS is used only a few places in a lap. But from 2014, all of the energy from fuel and battery is so precious that we will have to identify where deployment of the energy will be beneficial over the whole lap, and where saving will be least harmful for lap time. We call it "power scheduling". This will be decided jointly between the chassis teams' vehicle dynamics departments and Renaultsport F1 in Viry-Châtillon.'

"Next year's F1 cars will probably be the most fuel and energy efficient machines on the road"

This power scheduling – or energy flow – will be a key component in Formula 1 in the future. While it may be a struggle to explain it to the general public, it certainly has the potential to genuinely improve the on-track action.

'Choosing the best split between the fuel-injected engine and electric motor to get the power out of the power unit will come down to where operation of these components is most efficient,' says Tokunaga. 'But again, SOC management presents a constraint to the usage of the electric propulsion. And the optimum solution will vary vastly from circuit to circuit, dependent on factors including percentage of wide open throttle, cornering speeds and aerodynamic configuration of the car.

'There are quite a few components which will be directly or indirectly controlled by the energy management system – namely the internal combustion engine, the turbo, the ERS-K, ERS-H, battery and then the braking system. Each has their own requirement at any given time – for example the operating temperature limit. There can also be many different energy paths between those components. As a result, the control algorithm can be quite complex to develop and manage. What is clear, however, is that at any given time, as much energy as possible – which would otherwise be wasted – will be recovered and put back into the car's system. It would not be an over-estimation to state that the F1 cars of next year will probably be the most fuel and energy efficient machines on the road.'

The current breed of cars all have the MGU located at the front of the engine, under the oil tank, where it acts on the crankshaft directly. At the launch of the RS34 at the Paris Air Show, it was immediately apparent that the MGU-K had been relocated from the front of the engine to the side of it. This is a notable difference, not only to the 2013 layout, but also to the renderings of the 2014 Mercedes power unit which have been released so far.

But White feels that the relocation is simply a case of moving the MGU back to its logical location.

'It's more a case of why was the V8 MGU mounted where it was? And the answer to that is simply because we had to graft it on – it wasn't integrated from the beginning. There is a regulatory requirement – a legality box – that everything has to fit inside. There is a plane in front of the engine and a plane at the back of the engine with additional bits where the oil tank will be. We could have put the MGU on the front, but we chose not to.'

The MGU-K now sits underneath the exhaust manifold and drives the crank via a series of gears on the rear of

NOW AND THEN...

	RS27-2013	ENERGY F1-2014
ENGINE		
Displacement	2.4-litre	1.6-litre
Rev limit	18,000rpm	15,000rpm
Pressure charging	Normally aspirated, pressure charging is forbidden	Single turbocharger, unlimited boost pressure (typical maximum 3.5 bar abs due to fuel flow limit)
Fuel flow limit	Unlimited, but typically 170kg/h	100kg/h (-40%)
Permitted fuel quantity per race	Unlimited, but typically 160kg	100kg (-35%)
Configuration	90 degree V8	90 degree V6
Number of cylinders	8	6
Bore	Max 98mm	80mm
Stroke	Not regulated	53mm
Crank height	Min 58mm	90mm
Number of valves	4 per cylinder, 32	4 per cylinder, 24
Exhausts	Twin exhaust outlets, one per bank of cylinders	Single exhaust outlet, from turbine on car centre line
Fuel	Indirect fuel injection	Direct fuel injection
Number of power units permitted per driver per year	8	5
ENERGY RECOVERY SYSTEMS		
MGU-K rpm	Unlimited (38,000rpm)	Max 50,000rpm
MGU-K power	Max 60kW	Max 120kW
Energy recovered by MGU-K	Max 0.4MJ/lap	Max 2MJ/lap
Energy released by MGU-K	Max 0.4MJ/lap	Max 4MJ/lap
MGU-H rpm	-	>100,000rpm
Energy recovered by MGU-H	-	Unlimited (> 2MJ/lap)

the engine, while the MGU-H is housed behind the turbocharger and is linked by a shaft. It sits between the cylinder heads. Both MGUs are liquid-cooled direct current designs. In 2013 the Renault RS27 V8 is fitted with two different specifications – one developed independently by Williams, and the other used by everyone else.

This kind of team-specific development is unlikely to take place from 2014 onwards. 'Currently we believe that such variations would be forbidden by the regulations,' says White. 'It's not finalised, but there's no more discussion on the subject.' The performance of the new MGUs and the whole hybrid system is substantially higher than the current KERS used on the cars, and can be used in a variety of modes. 'Both MGUs have a much higher duty cycle than current KERS by an order of magnitude,' White explains. The current KERS has a 60kW maximum, but on average it's only a little over six, so it's a very small duty cycle. In 2014 the MGU-K has 120kW. Obviously we use all of the 4MJ allowed from the battery – that's already 10 times more than we use today – and the energy that arrives direct from the MGU-H is unlimited, so that's on top.'

The MGU-K's position on the side of the engine highlights another key element of the new power units: thermal management. 'These higher duty cycle MGUs need more cooling than the current units,' adds White. 'Where the MGU-K is there will be some radiant heat, but it is in our interests to keep as much heat as possible inside the exhausts so it can find its way to the turbine.'

The engine shown off in Paris was the real thing, but it was fitted with exhausts that were only indicative of the team-specific designs that will be run in reality. Each manifold is shrouded to prevent the escape of heat from the pipes, with a carbon fibre outer skin. Carbon fibre is not known as being especially good at dealing with high temperatures, as the amount of scorched bodywork witnessed during the 2011 and 2012 seasons will attest. But there are some new high temperature composites on the market, such as the Pyromeral Systems range, which could have some role to play. On this White will not be drawn.

'The exhausts you see on this engine are typical and representative rather than a definitive spec. They will be different on each car,' he says. 'They will have substantial insulation, but what is next to the exhaust pipe might not necessarily be carbon. Keeping heat in is the priority.'

White also did not want to be drawn on exhaust materials too much, but did admit that they would be nickel-based alloys – materials such as Inconel – although they may have to deal with higher temperatures than the current designs.

Despite only having a 1.6-litre internal combustion engine at its heart, the new power units are noticeably larger than the current 2.4-litre V8s due to all of the additional subsystems. Integrating this complex powertrain into the notoriously compact rear end of a modern grand prix car is going to be a major challenge for both engine suppliers and teams.

RAISING THE VOLUME

'The sound of the engine is the sum of three principal components: exhaust, intake and mechanical noise. On fired engines, exhaust noise dominates, but the other two sources are not trivial and would be loud if the exhaust noise was suppressed and contribute to the perceived sound of the engines in the car.

All three sources are still present on the V6. At the outset, there is more energy in each combustion event, but there are fewer cylinders turning at lower speed and both intake and exhaust noise are attenuated by the turbo. Overall, the sound pressure level – and so the perceived volume – is lower, and the nature of the sound reflects the new architecture. The car will still accelerate and decelerate rapidly, with instant gear shifts. The engines remain high revving, ultra-high output competition engines. Fundamentally the engine noise will still be loud. It will wake you from sleep, and circuit neighbours will still complain. The engine noise is just a turbocharged noise rather than a normally aspirated noise: you can just hear the turbo when the driver lifts off the throttle and the engine speed drops. I am that sure some people will be nostalgic for the sound of engines from previous eras, including the preceding V8, but the sound of the new generation power units is just different. It's like asking whether you like Motörhead or AC/DC. Ultimately it is a matter of personal taste. Both in concert are still pretty loud.'

Rob White, deputy managing director (technical) – Renaultsport

You can hear the Renault power unit running on the dyno at **www.racecar-engineering.com**

"The higher duty cycle MGUs need more cooling than current models"

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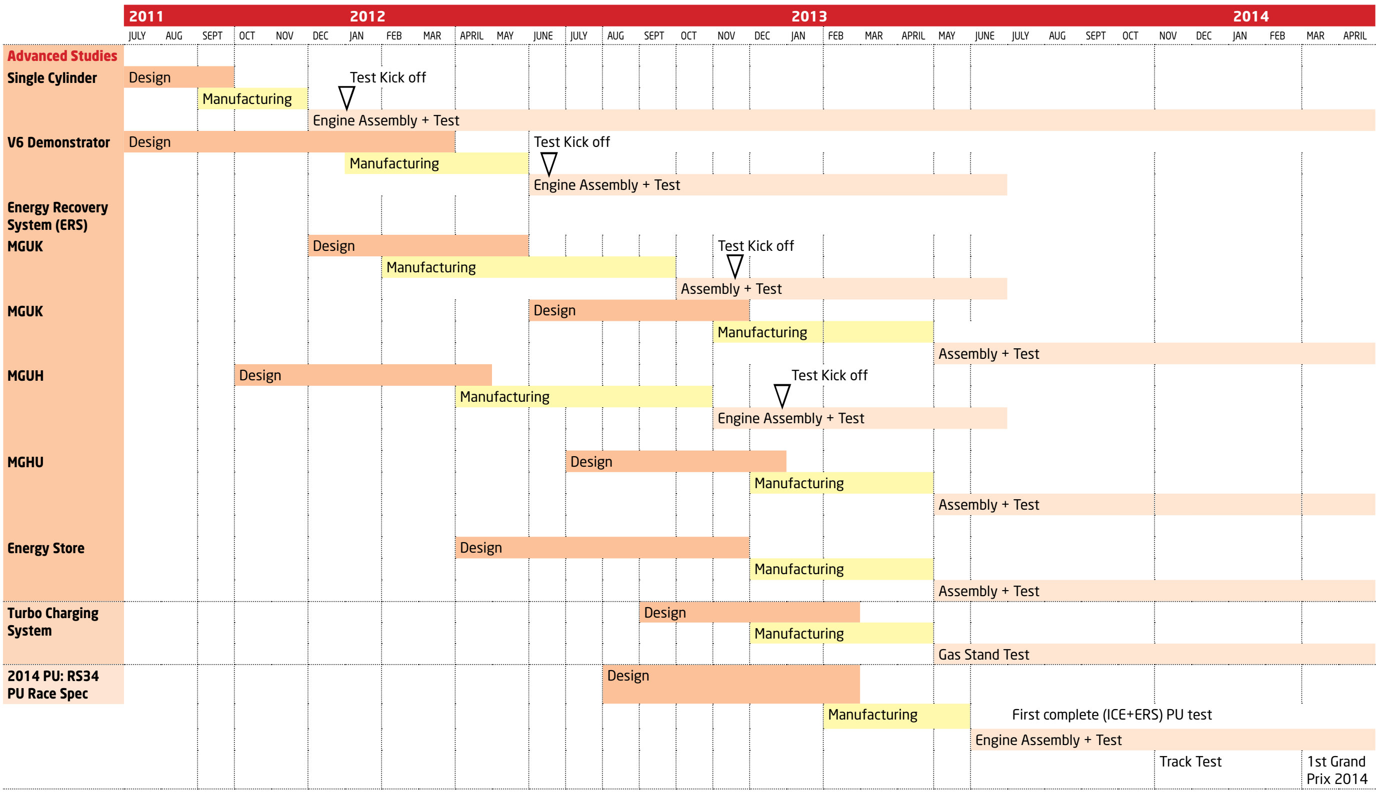
THE CHANGING PACE OF DEVELOPMENT



'Exchanges between chassis and engine teams started at a very early time, before the regulations were fully defined,' explains Renaultsport F1 director of programmes and customer support, Axel Plasse. 'From that stage, one of the key areas we needed to investigate was the packaging of the power unit. The current V8 is 95kg, or 100kg if you add the weight of the MGU. This increases to 120kg when you include the ancillary parts, such as the radiators and other cooling devices. With the 2014 power unit, the V6 turbocharged engine will be a minimum of 145kg, plus 35kg for the battery. At 180kg, this is a 80 per cent increase over the current units, plus a further 20kg for the ancillaries such as the intercooler and other radiators.'

The additional weight is partly compensated for by an increase in the minimum weight of the overall vehicle to 685kg, and the weight applied on the front and rear wheels must not be less than 311kg and 366kg during qualifying, giving a window of just 8kg.

'The power unit is much more integrated and central to design,' says Plasse. 'For example, the turbo overlaps the gearbox so that it intrudes into the space where there was a clutch or a suspension part. The energy store is also much larger, which has an impact on chassis length, fuel volume and radiator position, among other items.'

Every time a major rule change is introduced into Formula 1, it has the tendancy of reshuffling the pack. The Red Bull team, for example, took advantage of the introduction of the current regulations in 2009 and has dominated ever since. But that dominance could end next season. 'At the start of the year there will be people who have got it right and people who have not,' Horner admits. 'The beginning of 2014 is just the beginning – it's all about development through 2014 and 2015. That's where there will be a lot of competition between the engine menufacturers. We think that Renault has the right people to develop the engine and the engine manufacturers have the ability to react. But if it is two seconds a lap slower than the best engine, we are in the shit.'

But that ability to react is likely to be limited in 2014, according to White. 'I think we are heading for a homologation process identical to what we have now,' he says. 'We will have to provide an engine before the start of the season and a legality dossier, and we will not be able to modify the spec of the engine during the homologation period. I think year-on-year change will be permitted within the scope of the sporting regulation though. The scope of the homologation perimeter will be much bigger too, covering the MGUs and energy storage.'

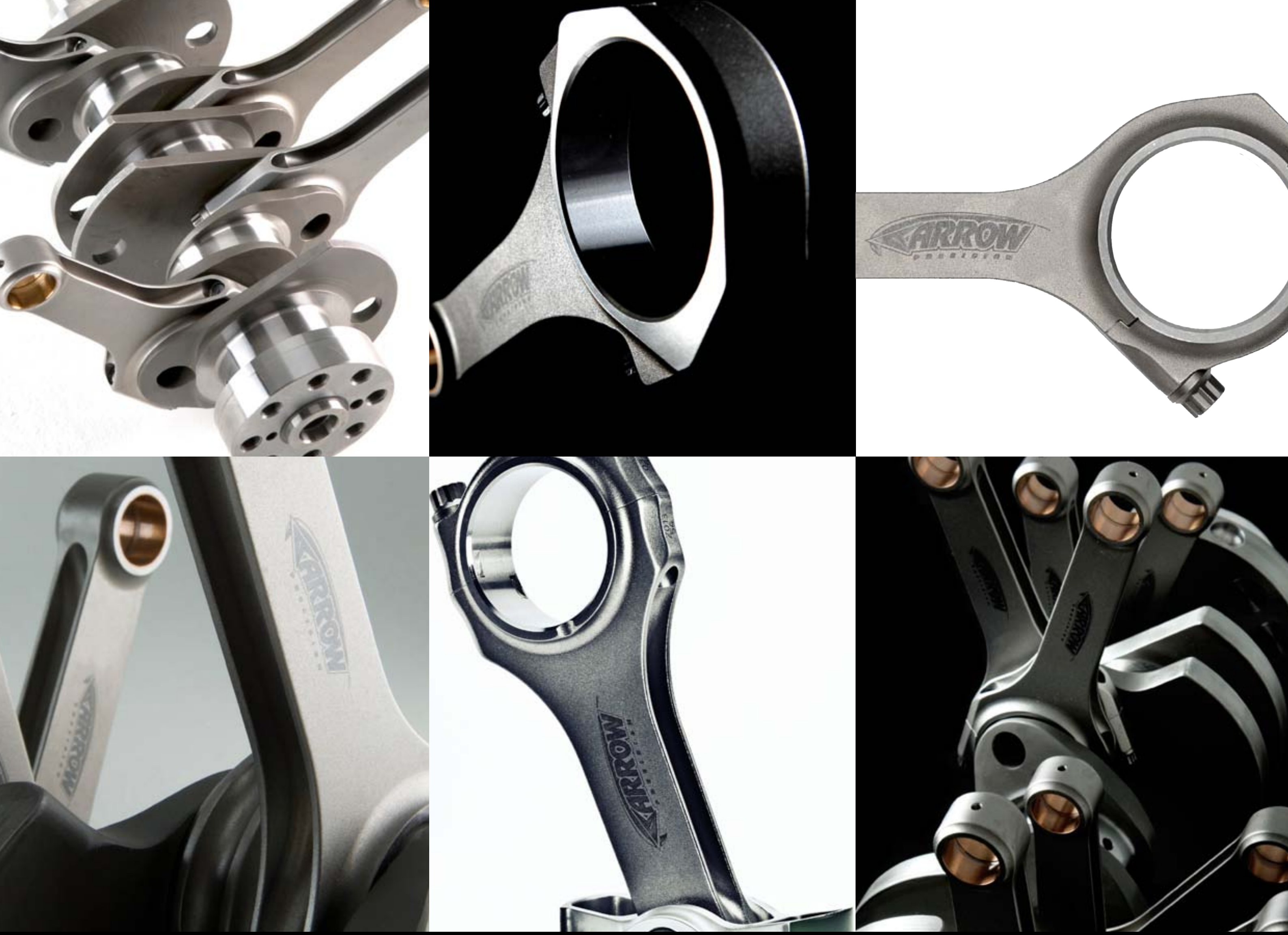
But with teams and engine suppliers still able to work on many areas outside that perimeter, things like the exhausts and installation can be changed. So can the hoses, hydraulics, air intakes and other areas which can directly affect the engine's performance and – most importantly – there will be far more freedom in the car's electronic system than there is currently.

'It's not beyond the wit of man to imagine that there will be significant performance enhancements as we learn more about managing the life cycle of the power units and the life limiting factors,' says White. 'That's not about changing the spec of the engine, but how we use it. Each engine that is built is done so to a unique build spec and there is scope to modify that. We can request permission from the FIA to make changes, but only for certain reasons.'

The final challenge for some teams is financial. The new power units are reported to be very expensive, and with some teams already struggling with costs, it could prove too much. Horner, however, is not overly concerned about it. 'With any change in regulations, the price only ever goes up,' he says. 'Hopefully the costs can be contained. But we do know that for the independent teams it's a big ask at a difficult time.

'But is there ever a good time to introduce new technology?'

"At the start of the year there will be people who have got it right and people who have not. But it's all about development through 2014-2015"


ARROW

The technology of a 1990s F1 cylinder head

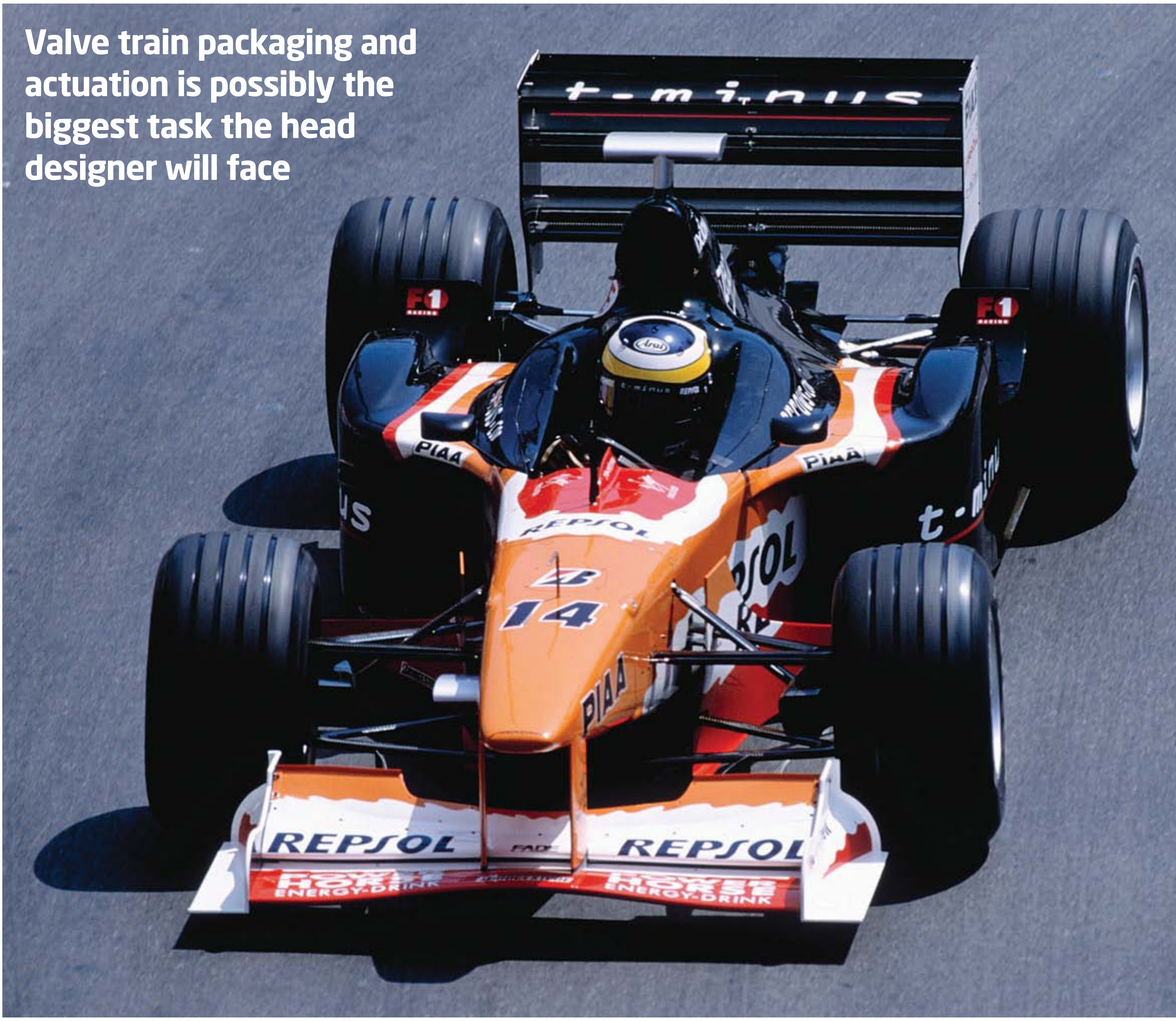
It's a common source of breakdowns – but then this is a part where lots can go wrong...

BY BRIAN GARVEY

Unquestionably, when you're trying to build a high-performance engine, the cylinder head is one of the key items. The most important thing about a good cylinder head is of course good air flow, but there are many other demands placed on a Formula 1 head that are less evident without closer inspection. When an engine breaks down during a race, it is the cylinder head that is at fault, and there are a multitude of points that need to be addressed concerning the design and manufacture of this complex part.

A key aspect with good head design is uniformity across all cylinders. When it comes to the ports themselves, and airflow through them, this isn't too much of a problem, but coolant flow and management around said ports and through the head can be. It is critical that no stagnant areas exist within the coolant galleries as these can lead to hot spots around the combustion chamber. On a normal road car, coolant normally enters the head at the gasket face from cylinder block and then exits

Valve train packaging and actuation is possibly the biggest task the head designer will face

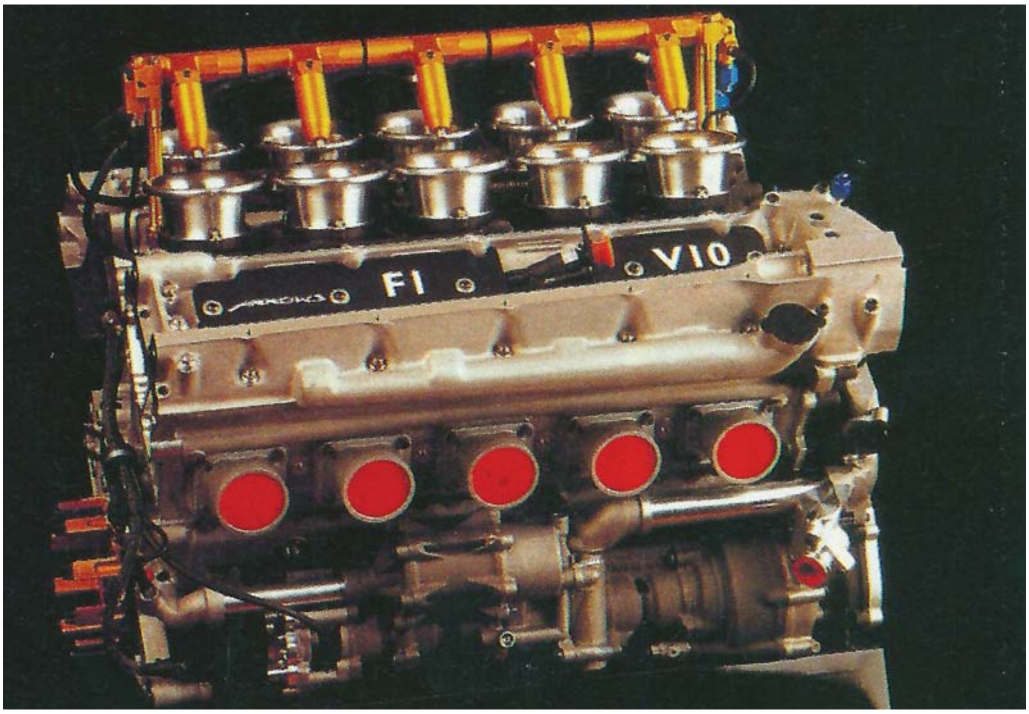


the head casting at one central point. On an F1 head, the cooling of the combustion chambers is stricter and the galleries above them are constructed in a more modular fashion. This ensures better thermal balance across all cylinders and their combustion chambers. Since the engine in an F1 car is also a stressed member, this too has to be taken into account when designing the head castings. Considerable tension and compression forces are exerted through the heads so they have to be constructed to resist these loads without distorting, while at the same time being as light as possible. Valve train packaging and actuation is possibly the biggest task the head designer will face along the way. Above certain rpm, pneumatic valve springs are called for. Last of all, and just as important as coolant management, comes valve train lubrication. With cams spinning at speeds up to 9000rpm, and with each valve opening up to 150 times a second lubrication needs some serious thought too.

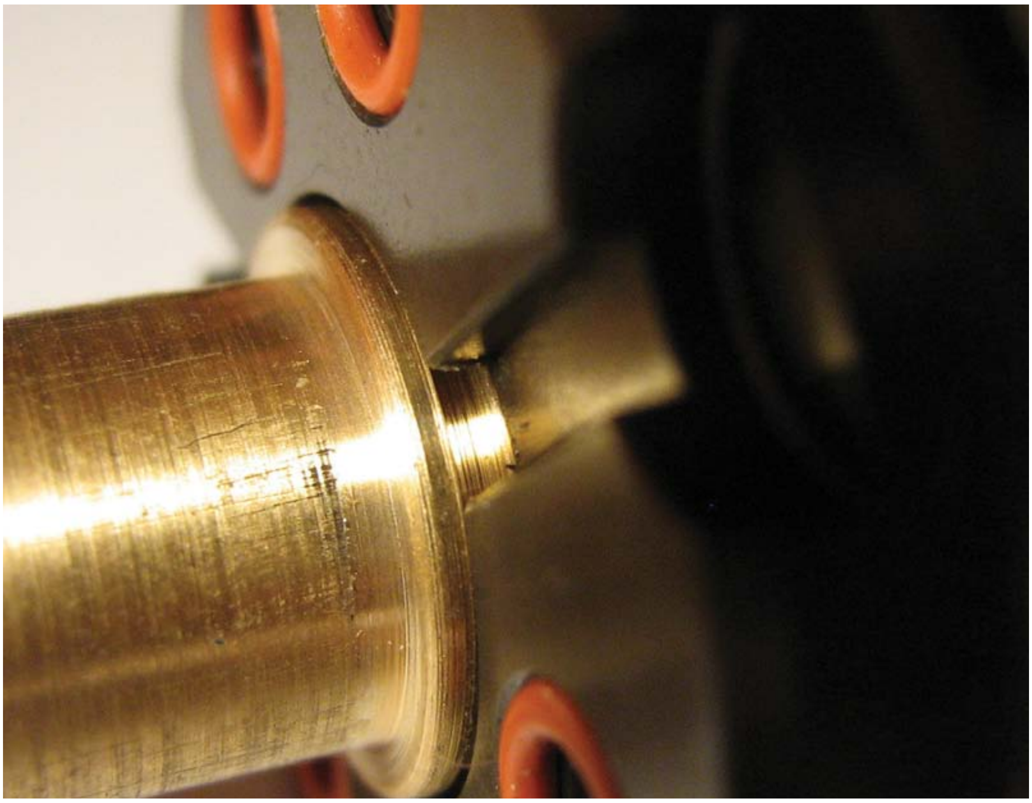
With all of the above in mind, let's dig a little deeper inside an F1 cylinder head in order to discover how some of these hurdles were overcome and also uncover some never-seen-before spring technology. The head in question is from a 3-litre V10 engine, designed by Brian Hart and used in Formula 1 in the 1990s. It features modular-style waterways, bucket tappets, ladder-style cam cover, in-cam oiling, pneumatic valve springs, single barrel throttles, tappet face oil squirters, and is taken from an engine with a rev limit of approximately 18,000 rpm, and which developed in the region of 800hp.

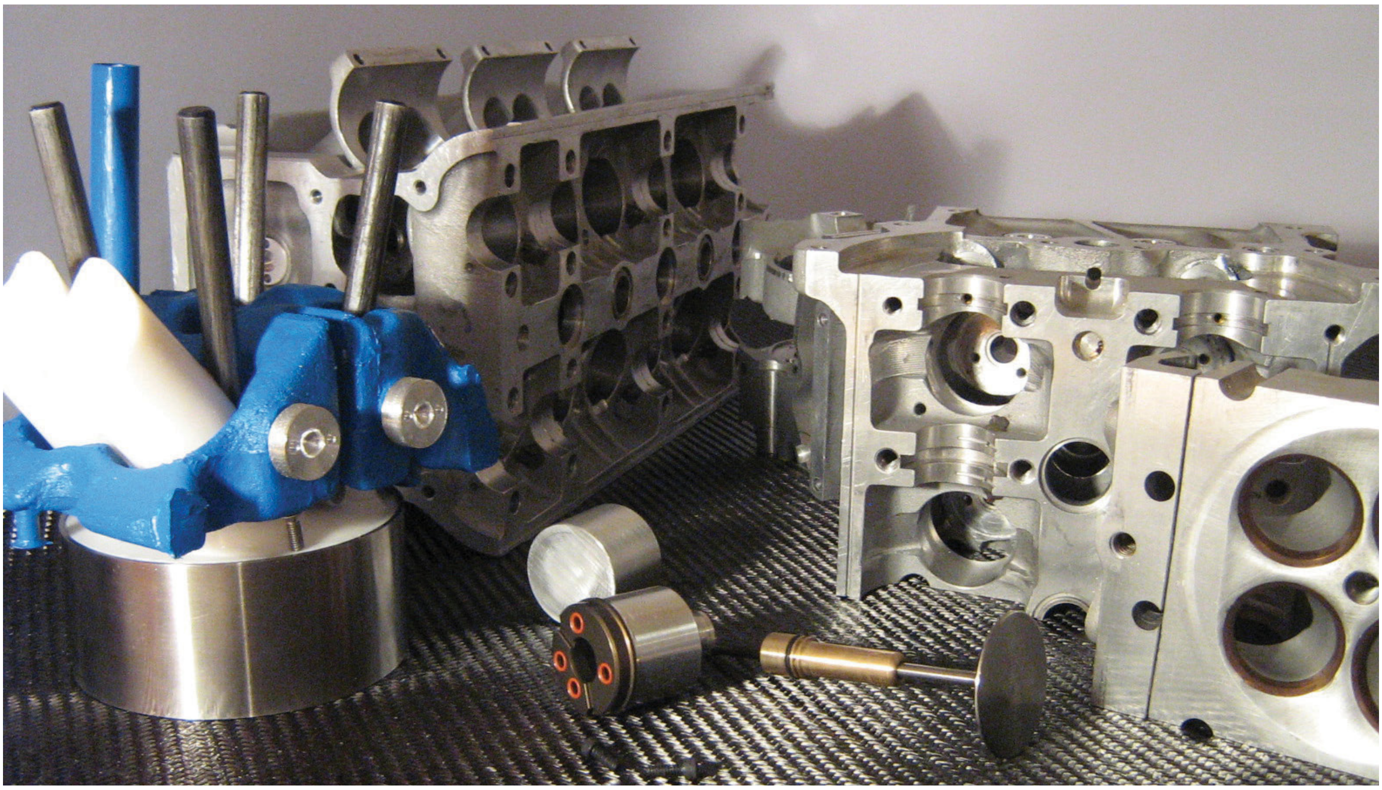
In order to accurately display the internal architecture of the cylinder head, an internal model of the coolant waterway above the combustion chamber is required. The head therefore needs to be sectioned and a silicone mould taken of the internal water passages. This

The Arrows A20, featuring Hart's V10 engine, in 1999



The Arrows T2 V10 engine





A critical part of the design of a Formula 1 engine involves the cylinder head, and the pneumatic valve has been a major breakthrough

single silicone model reveals not only the coolant distribution, but also how the cores are laid out within the main sand casting. In order to form the waterways within a cylinder head, sand cores need to be placed at exact locations within the main casting which later get washed out once the aluminium has solidified. These cores are made from special fine sand mixed with a binder agent which hardens once cured – binding the sand together. This enables the cores to be handled and placed accurately within the mould without fear of collapse. The cores are located on to 'core prints' in the main sand moulds – these are basically 'hangers' which hold the cores in place while the mould is being filled. Evidence of these hangers can easily be seen on the silicone model. They are also a common sight on nearly all road engines and become the locations of the frost plugs once the block or head has been finished and machined. The same can be seen on the F1 cylinder head where the locations of the core hangers have been drilled, tapped and plugged up with aluminium bungs. With this waterway core model you will also notice something else if you look closer – all the cores are identical across the full length of the head. This leads to even coolant distribution per cylinder, and it also means that only one small core box is needed to make all the cores. Once hard, they can all be bonded together ready for placing. While cores are indeed joined at the sides, which in turn form communication paths for coolant between galleries, the main flow takes place from bottom to top. The location of the core hangers on the core model, as well as the finished bung positions are displayed also. The location of the hangers on the end core lie in the same locations of the core behind it which is bonded to the adjoining core. Oil to the cylinder head is fed into the block into a large radial groove at the end cam journals. Here the oil enters the centre of the hollow camshafts through drillings where it then flows along the length of the cams and exits at each journal though more drillings to provide the necessary hydrodynamic lubrication. An oil groove is formed partway around the lower half of the cam journal, which takes some oil from the live oil drillings inside the rotating cam and feeds it out through small squirters aimed at the tappet and cam lobe surfaces. In-cam oiling also frees up space within the cylinder head casting that would normally be needed for oil galleries. It soon becomes apparent at this stage that high performance and reliability comes with great uniformity in terms of coolant and oil management.

The relationship between the intake and exhaust ports and the surrounding coolant passages can be displayed if another silicone model is taken. Since greater coolant flow is required around the hotter exhaust ports coolant from the block is introduced into the gallery directly below the exhaust port floors through two 8.5mm holes. On the intake side, coolant enters below just one intake port through one 5.5mm hole. The geometry at the highest point of the coolant gallery above the intake ports directs any trapped air towards the exit tubes leading to the tapered coolant pipe cast into the ladder style cam cover. In the case of this cylinder head, the valve centre lines are angled in both directions. While angling the valve centres on one axis is common on most engines, angling the valves on both axes is not. This offers advantages in that it opens up space for a wider journal located between the tappet bores, while at the same time giving more clearance between the bore wall and open valve face. This leads to a better and more stable oil film, and also cuts down on bore shrouding. The area surrounding the sparkplug also requires good coolant flow. One of the main reasons small diameter sparkplugs are used in F1 is to eliminate all chances of the material that makes up the counter-bore for the plug becoming part of the port wall material – which inhibits coolant

Above a certain rpm point, normal valve springs become useless – so pneumatic springs are called for

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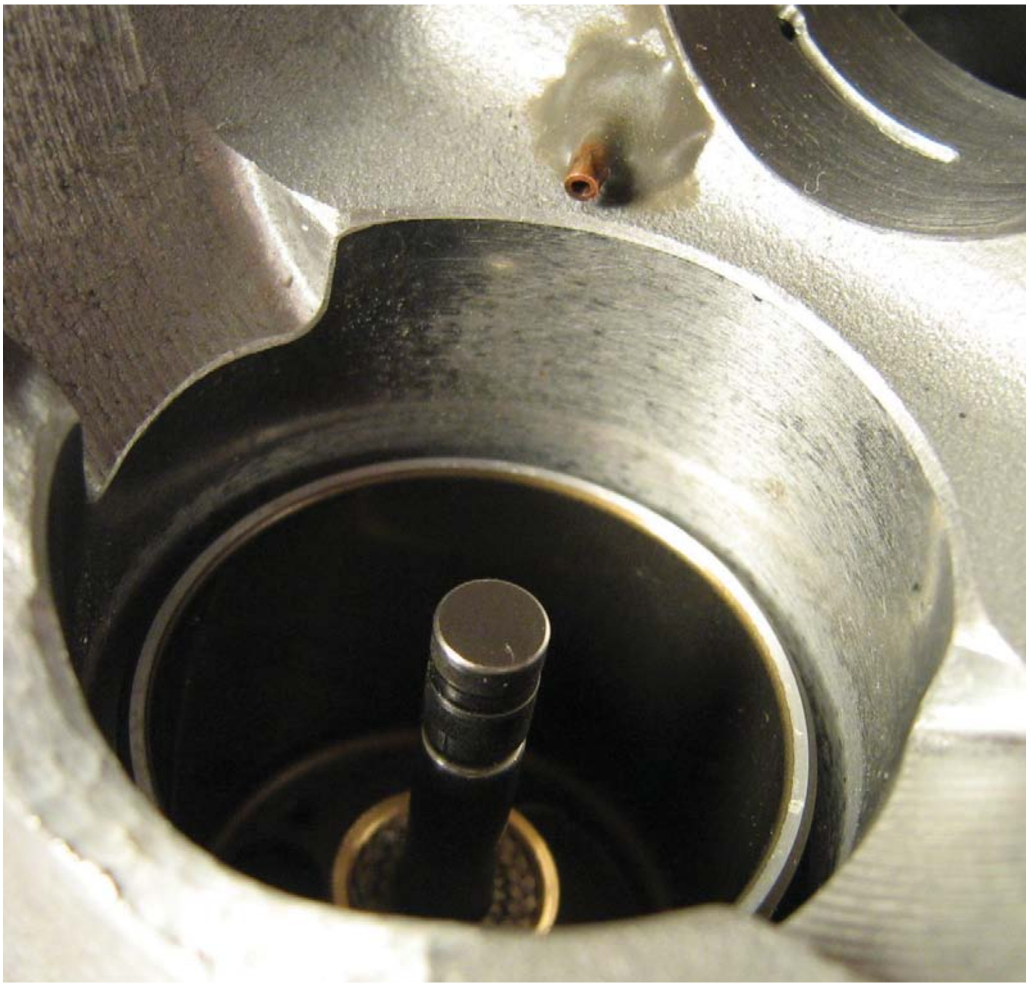


flow around this area. One last point the head designer needs to keep in mind when setting out the initial design and internal layout is the head studs, and of course access to the nuts. In the past, some F1 engines have featured a two-piece design where the main head section was first bolted on to the block, then a cam tray containing all the valve train was bolted on top of this. Had it been all cast as one unit, the location of valve train parts would have prevented access to head studs. This is less common nowadays since the point at which both parts meet was another possible leak area that also required considerable care when machining to closely match the two parts. It more often than not weighed more too – an important issue considering its distance from the roll centre.

This takes us to the pneumatic valve train. A normal wire spring, simply a torsion bar wound in coil form, can only have so much stress imposed upon it before it fails. You can increase endurance levels by going with beehive or indeed two springs. Springs go into resonance at a certain rpm, because they have mass and stiffness - valve bounce. Two springs allow different frequencies and an interference fit between the springs provides damping. Pneumatic springs are simply low rate, high static load, zero mass springs. To enable designers to cross this barrier, a different type of spring actuation was required in order to return the valve to its seat without float or spring failure at extreme rpm levels. Enter the pneumatic valve spring. The concept is relatively simple, however its execution is not. Inside an F1 engine, the demands on this assembly are far greater than seen in road cars, as you can imagine. Exotic materials and countless hours of testing are required to even get to prototype stages, and every year designs get improved on for better reliability. A pneumatic valve spring design, regardless of whether it sits under a tappet or finger follower, comprises of a cylinder and a piston. The cylinder is attached firmly to the head, while the piston is attached to the top section of the valve stem. Air under pressure supplied to the cylinder causes the piston to rise and return the open valve to its seat. This all sounds relatively simple until you consider the conditions these parts are required to work under. With the valves opening up to 150 times a second with an average lift of 15mm, at temperatures in excess of 100degC, piston seal choice and surface finish of sliding parts becomes a major chore in the research and development department. Engine failure, as mentioned at the start of this technical bulletin, more often than not originates from the failure of these seals – the system is charged from a tank of pressurised gas which is of fixed volume and is not regenerated onboard the car. A single leak therefore has disastrous consequences for the engine. All pneumatic cylinders are fed up from a continual drilling through the length of the casting. In total there are eight seals needed in each pneumatic valve spring assembly – two of which are sliding seals, the other four being static O-ring seal arrangements.

A single leak in the piston seals will have disastrous consequences for the engine

The first of the sliding seals is situated in the piston itself where it seals against cylinder bore, the second sliding seal resides in the top of the valve stem where it provides a seal with the valve stem. The other four seals are used around cylinder fixing holes, air feed hole, and valve stem hole through the piston. This amounts to a total of 80 seals just in the pneumatic spring assemblies alone. One of the most critical features with such dry sliding seal design we see here is surface finish on the bore walls. It must resist corrosion during periods while the engine is being built, being stored, or is in transit. The cylinder features hardcoat anodic coating internally and externally on the base. The outside has been machined down for tappet skirt clearance. The anodic coating also benefits in terms of lessening sliding friction when impregnated with PTFE. The beryllium copper valve guide contains a groove just below the cylinder sealing O-ring. Excess oil delivered by the tappet squirters finds its way down and flows in a channel cut into the piston base which is located at the highest point when mounted. It flows around the valve guide, further cooling the guide and valve stem before flowing back out at the lower groove. With this information now displayed it is easy to see why F1 engines will always remain a cut above the rest in terms of design, construction, materials, and innovation.

The making of Audi's mini marvel

When 5.5-litre engines were outlawed ahead of Le Mans 2011, the German marque set off on an alternative route to glory.

BY SAM COLLINS

Downsizing was the buzzword when Audi Sport was developing its new engine for the 2011 Le Mans 24 Hours. The ACO had outlawed the big 5.5-litre engines used previously and forced the manufacturers to think small. For diesel engines, the upper displacement limit was set at 3.7 litres and the maximum number of cylinders set to eight, while petrol engines were restricted to normally aspirated 3.4 litres and 2-litre turbo.

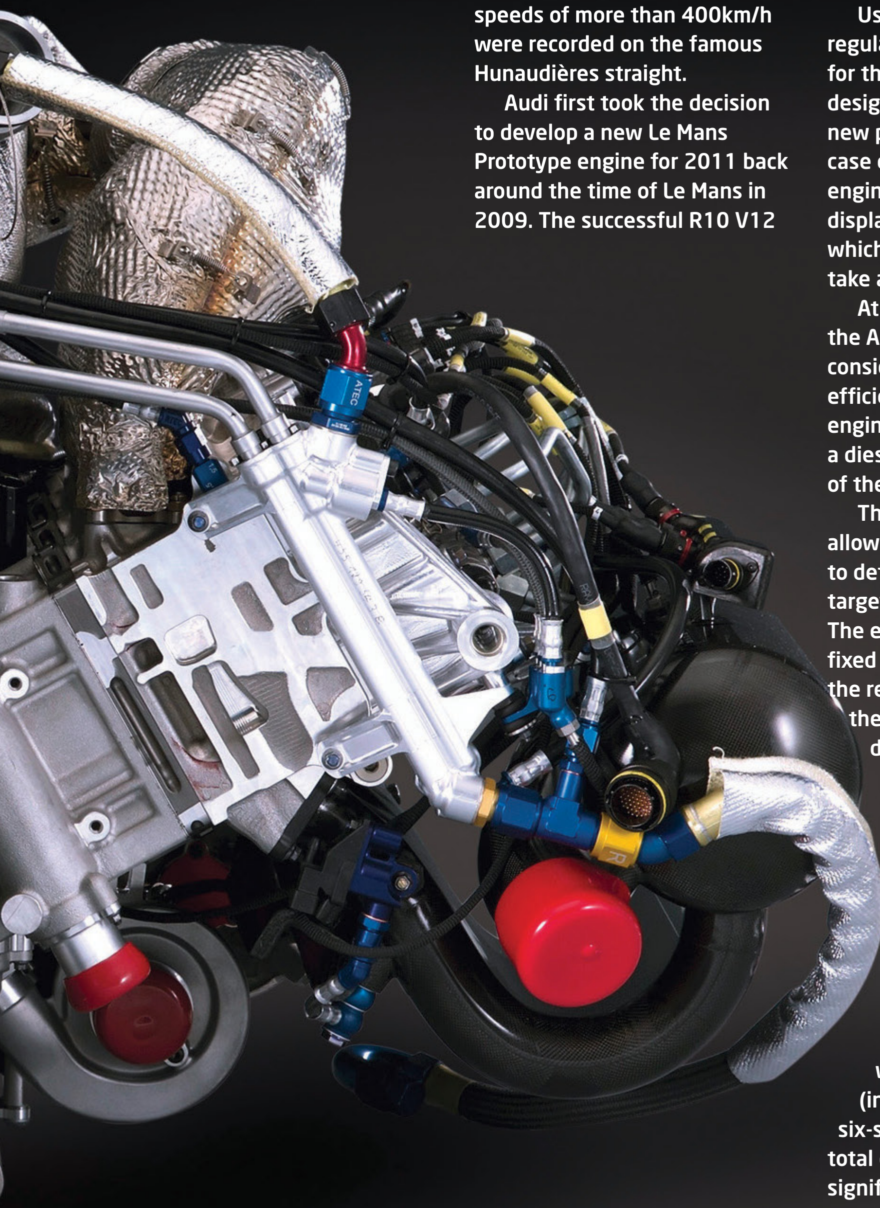
The reasons for this reduction on the maximum capacity for diesel engines were primarily those of safety and equivalency. Concerns were being raised about the speed of the works LMP1 cars as Peugeot and Audi were locked in a development war. This led to a dramatic reduction of the lap times in qualifying, but also increasingly during the race to within striking distance of the 'eternal' record of 3m 14.8s from 1985 where maximum speeds of more than 400km/h were recorded on the famous Hunaudières straight.

When design work began, with no rulebook fixed, engineers were left to take a gamble

Audi first took the decision to develop a new Le Mans Prototype engine for 2011 back around the time of Le Mans in 2009. The successful R10 V12 and R15 V10 predecessors supplied a starting point which allowed the German engineers to develop the new unit in just 20 months. For the new design, it was imperative to assess whether the chosen concept, which explored previously unknown technical territory in many aspects, could also be successfully developed in the short development time.

Usually the engine regulations and rulebook for the car are fixed before design work begins on a new project but in this case only 'guidelines' for engine power and maximum displacement had been issued, which left the engineers to take a gamble.

At the start of the project the Audi Sport engineers considered using a high efficiency spark ignition engine, but again opted for a diesel after early evaluation of the concepts.



The 'guidelines' issued allowed the Audi engineers to define some performance targets for the new engines. The expected power was fixed as a broad premise in the regulations - such as they were. The restrictor diameter was also defined accordingly in the same rules, and the operating range along with the maximum boost pressure were effectively predefined. So, the targets set were: power exceeding 520PS (382kW), torque greater than 900Nm in a wide, useable RPM range (in order to be able to use a six-speed gearbox efficiently); total engine weight significantly less than 200kg, and stiffness when installed in-car as a fully stressed design, with supporting elements. The restrictor diameters and boost pressures were reduced still further for 2011. This resulted in a power and torque reduction and a slight shift of the power point in the rev range.

The next question was; what size and shape would this engine be? The definition of the number of cylinders was also on the agenda at the beginning of the concept stage. An eight-cylinder engine would have had the advantage of being able to transfer the enormous amount of experience gained from the area of the 12-cylinder R10 engine. However, Audi was convinced that a six-cylinder block had greater potential with regard to frictional losses, weight and compact dimensions. The targets for the new engine resulted from the demands to reduce engine dimensions and to be able to change the car's weight distribution. The overall dimensions of a 3.7-litre V6TDI engine showed the advantage of its shorter length, but a V8 engine could be fitted lower in the car achieving lower height and width dimensions.

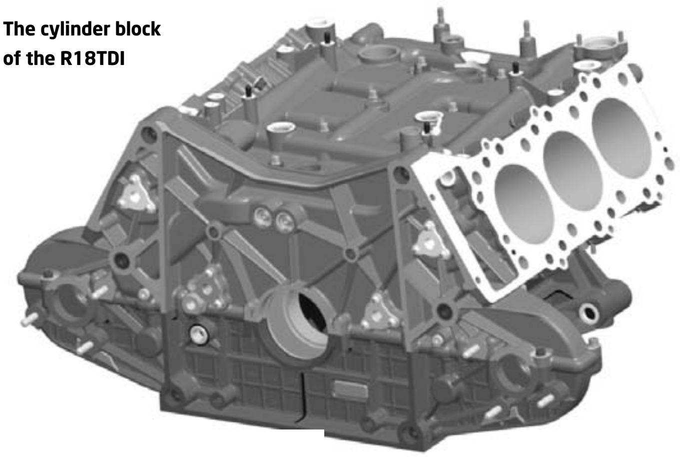
The regulations also permit engines with a capacity of less than 3.7 litres. With the weight and size of the engine crucial to overall car performance, a smaller capacity was also considered but - as was the case with the R15 engine - the choice of a 3.7-litre displacement was made with the underlying intention of keeping the specific load as low as possible. With increasing displacement, the engine's effective mean pressure sinks for the same attainable power (air mass).

The next step was to design a block. It would have to be as compact as possible and lightweight. Its design is also heavily influenced by many other factors. In order to reach the weight target, the majority of the engine had to be manufactured from light metal alloys and - at the same time - be able to withstand combustion pressures permanently above 200 bar.

The R18 V6 cylinder block is manufactured from hypoeutectic alloy

SWEPT VOLUMES FROM V12 TO THE V6TDI					
Displacement	5500	5500	5500	3700	3700
Cylinders	12	10	8	8	6
Swept volume	458.3	550	687.5	462.5	616,6667
Increase		20%	50%	0.92%	34.56%

SIZE COMPARISON BETWEEN THE V6TDI AND V8	
When V6 TDI 3.7 = 100	**V8 3.7-litre in comparison**
Engine length	18%
Engine width	-2%
Engine height	-7%

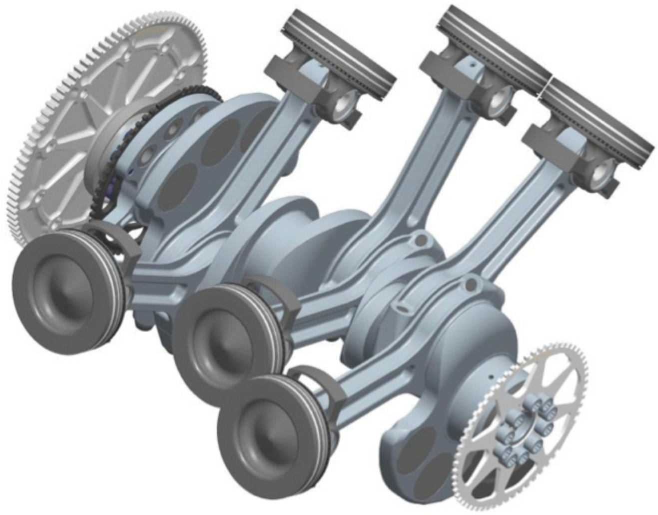


The cylinder block of the R18TDI

using the low-pressure sand casting method. The cylinders themselves are Nikasil coated. Completely new engine block architecture was required due to the large cylinder bank angle. The cast water channels, with a fork to the heat exchanger, have only a joint to the water cooler in an otherwise closed system. The relevant oil galleries are integrated in the block for piston cooling. The crankcase below the main bearing centre line – the so-called bedplate – is manufactured as complex, heavy-duty cast component. The precision casting blank has equally high strength (RM 35 MPa) and ductility owing to the directional solidification. The minimum wall thickness is less than 2mm.

The final block design featured a slightly long stroke as a result of piston loads, engine size/installed height and combustion chamber thermodynamics. The installation height of the engine is influenced substantially by the stroke. The stroke increased by five per cent when compared to the V10 and is accounted for by the increase in the crankshaft centre-line from the bottom plate. The 120-degree cylinder bank angle led to the Audi engine achieving a very low mounting position and therefore a low centre of gravity.

It was also designed specifically to suit the steel piston's lower compression height. Due to the larger bore of the V6TDI, the piston area loading is increased by approximately five per cent for the same ignition pressure. Meanwhile, the 120-degree cylinder bank angle is a result of the following points: lowering of the centre of gravity, layout and drive of ancillary components, firing interval and the mono-turbo exhaust layout. With this cylinder bank angle, the bedplate can still be connected extremely well to the crankcase. The cylinder spacing was adjusted to suit the increased bore so that the land width could be retained. As a result, the closed-deck engine block achieves the required stability.



The obliquely divided steel connecting rod is manufactured with an optimised profile and further refined with regard to stiffness, optimum dynamic bearing stability and minimum weight by FEM calculation

KEY ENGINE ELEMENTS

At the heart of the engine is the cranktrain, topped with some innovative steel pistons, which are one of the key elements of this engine. Due to the high piston loads generated in a race engine, the maximum load limit for the aluminium piston with a fibre-reinforced bowl rim was achieved during development of the V12TDI. Steel pistons were fitted to the R15 V10TDI from the very beginning. The larger bore and increased loads on the R18 V6TDI piston necessitated extensive analysis of the thermal management of the piston and piston rings.

The piston is manufactured from heat-treatable steel. This material combines the properties of high temperature resistance and good thermal conductivity with excellent machining properties. In addition to the higher temperature resistance, the steel piston has the advantage that the top-land is smaller than that of an aluminium piston. Owing to the greater transferable force in the pin bore, the gudgeon pin fitted to the steel piston can be considerably shorter, which in turn allows a weight reduction. As a result, a weight saving is even achievable when compared to the aluminium piston. The steel piston, made by Mahle, has a combustion bowl developed specifically for this application. The high thermal loads made the use of two piston spray nozzles necessary – one for the piston base and the other for the cooling channel.

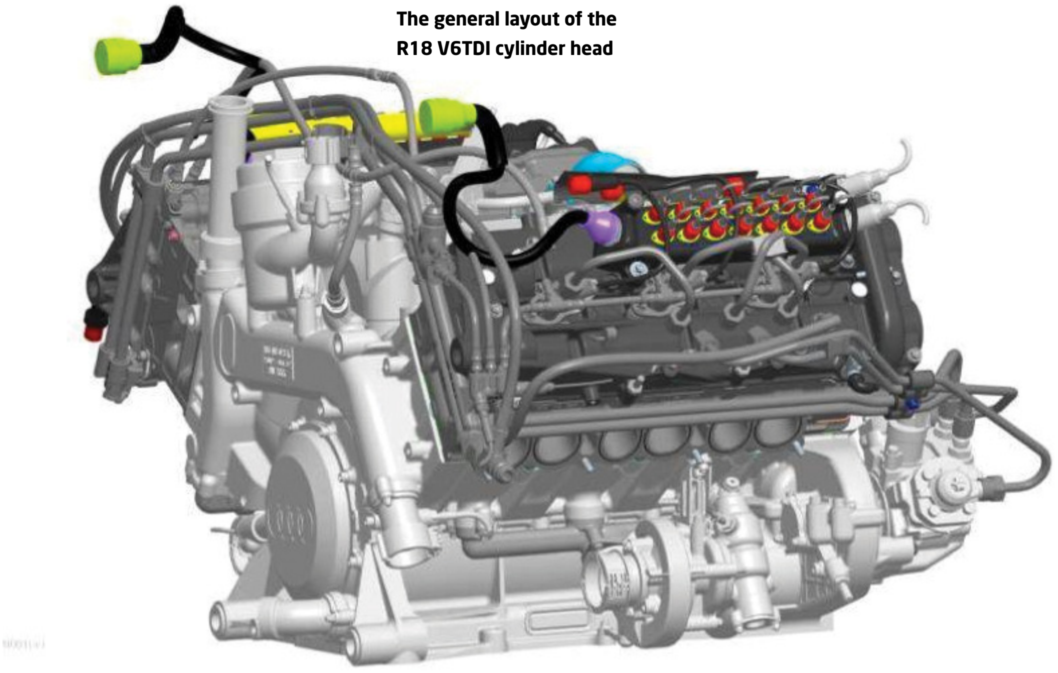
The reduction in displacement and number of cylinders led to a direct increase in the litre and/or cylinder power and therefore – inevitably – to higher piston loads. In conjunction with the extremely short development time of the engine, the reliability of the piston had to be proved by calculation at an early stage of the design.

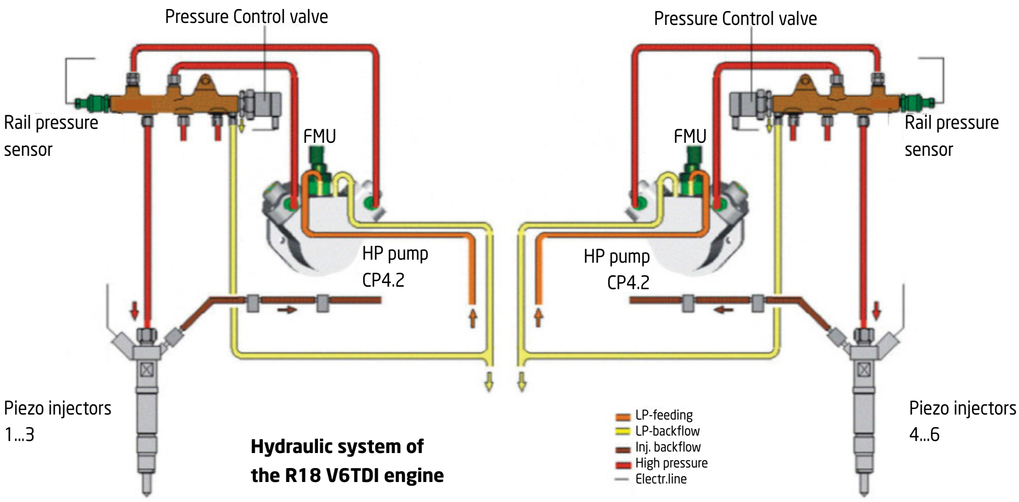
The design of the piston bowl, the lowest possible compression height as well as minimum weight are actually contrary to achieving the stiffest possible and operationally reliable design of the piston, which is subdivided into different disciplines. In addition to the actual stress analysis for the piston and liner (also from the tribological viewpoint), a perfectly functioning ring package is also required.

The crankshaft was designed around several key areas: the bearing load through the RPM range and load spectrum (ignition pressure and inertial forces); torsional and bending stiffness; free moments of the first and second order; vibration sensitivity and lightweightness.

Its essential dimensions were determined using bearing load and hydrodynamic lubrication gap calculations in conjunction with FEM. In this way, the diameter and width of the main and connecting rod bearings were defined according to operational demands, and

The general layout of the R18 V6TDI cylinder head





Hydraulic system of the R18 V6TDI engine

the crankshaft webs made for greater stiffness of the journal connection.

Because of the engine's design, the free moments of the first order acting outwards can only be minimised by balance masses on the crankshaft.

The weight target for the entire engine did not, however, allow complete balancing of the free moments, but the resulting vibrations caused by the imbalance are acceptable for a race engine. An additional weight on the front end of the crankshaft and an extra web ahead of the gear drive facilitate efficient compensation due to the large centre-to-centre distance. The crankshaft's stiffness is so high that a vibration damper could be omitted.

On the drive-side, a light steel flywheel transmits the torque to the clutch. Teeth with straight-sided serrations replaced the flywheel flange previously used. In this way a conventional, high-strength crankshaft gear could be used.

An incremental toothed gear positioned alongside the crankshaft drive gear supplies the impulse for the Bosch Motronic rotational speed signal. Another incremental toothed gear at the front end of the crankshaft gives a redundancy of the rotational speed recognition.

At the top of the engine the design owes a lot to its predecessors, especially the R15 V10 engine. In the first development stage, the cast aluminium cylinder head design was tested in a single cylinder engine. The basic single cylinder unit used in the development of the V10 was modified rather than a new unit built. Some of the components were created quickly using the rapid prototyping process to increase the speed of development. The single cylinder engine was used for the main tasks in the combustion process development, but was also used for endurance tests.

But it is not the case that the V10 heads were carried over to the V6, not least as they had two cylinders too many. Many areas had to be re-dimensioned due to the increased loads caused by the larger bore. The included valve angle was optimised and the valve enlarged so that the bore diameter could be used to its maximum.

Further development of the ports and port positions were verified together with the definition of the included valve angle on the single-cylinder cylinder head using flow boxes and simulation. The basis for this was the previous engine on which the systematic for the swirl flow optimisation was carried out.

VALVE TALKING

Two inlet valves and two exhaust valves are aligned parallel to the cylinder axis. The valve seat rings are manufactured from sinter alloys that were specially designed for the high loads. The valve guides are produced from copper-beryllium alloy. The valve gear consists of natrium-filled steel valves, conical valve springs and finger followers. The injector duct positioned centrally at the cylinder head middle is well supported by ribs in the oil chamber and therefore ensures a stable combustion chamber plate.

The cylinder head cover with the engine mounting points is machined from solid billet for strength reasons. Thanks to the integration of the camshaft bearings in the cylinder head cover, the cylinder head has a particularly high stiffness level in the upper area. This allows the introduction of suspension forces via the monocoque and/or the gearbox.

Through optimisation measures, it was possible to omit a mounting point between the cylinder head and the monocoque. In the area of the gear wheel housing, a part of the cover and the housing was replaced by a carbon-fibre part to reduce weight.

The camshafts are steel and are hollow drilled for weight reasons. The cam lobe profile was modified when compared to the R15 V10TDI. Greater cam lift and modified valve timing were required to optimise the new combustion process.

Because of the engine's short length, it was not possible to position the high-pressure injection pumps alongside

the engine on the timing gear housing. A radical change to the camshaft and pump drive was the result.

The gear drive was repositioned on the engine's power output face and the CP4 hydraulic pumps are located towards the rear.

The twin pump arrangement balanced the peak torque produced by the hydraulic pumps – but for increased weight when compared to the single pump design.

The layout of the gear drive on the clutch side of the engine ensures that the gear drive runs relatively smoothly, and that only low alternating torque occurs.

In addition to the camshafts, gears also drive the oil and water pumps and the high-pressure fuel pumps. The needle roller bearing steel gears are supported in the housing using floating axles. One floating axle per cylinder bank simultaneously assumes the function of compensating for tolerances and height differences in the cylinder head. The synchronously injecting hydraulic pumps are integrated into the gear drive with a ratio of 0.75. By reducing the drive speed, a high-load layout was possible for the highest injection pressures.

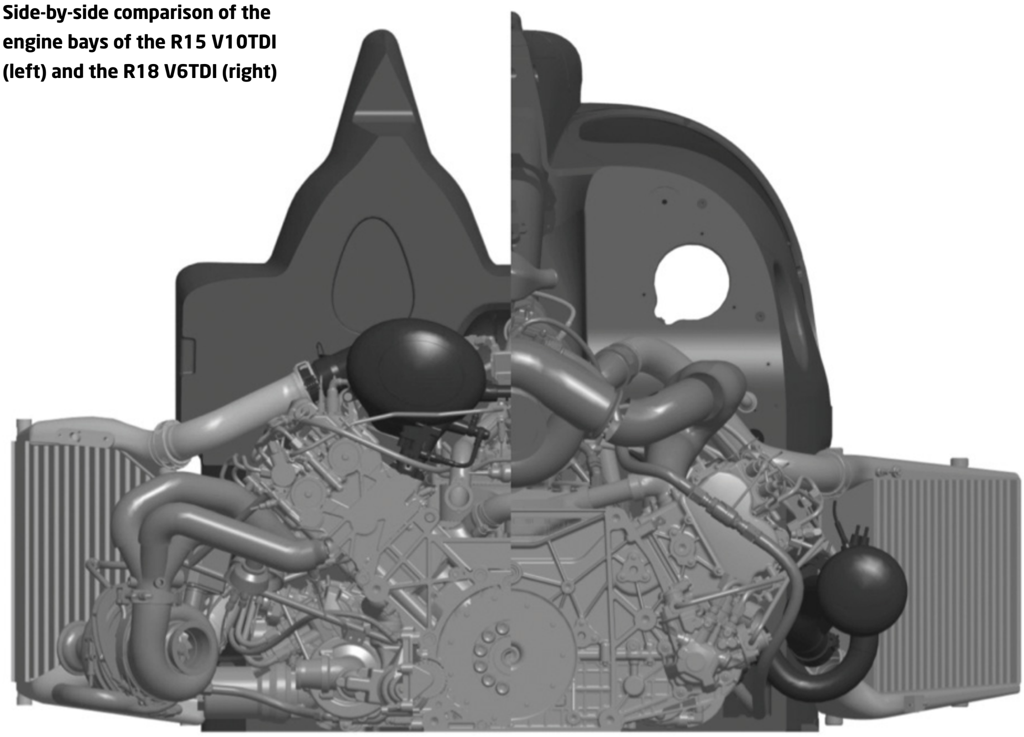
The piezo injectors are tailored to suit the engine. The nozzles were designed for the required output and tailored for the selected combustion process parameters through elevation angle, number of holes/type and nozzle protrusion. The low and high-pressure fuel systems are modified to suit the engine installation. Quick-release couplings in the feed and return circuits form the interface to the car. The fuel tank system with electric low-pressure supply pumps (lift pumps) was newly developed for the R18.

The inlet manifold length assumes a part of the charge exchange work, and is therefore a part of the engine calibration. In 2011, a relatively short inlet manifold equipped with a small plenum volume was used. The cross-sections are tuned to the inlet port area of the cylinder head. For 2012 the setup was reworked and a significantly larger induction manifold length used. The boost pressure monitoring system/sensors supplied by the organisers ACO/FIA are located on the inlet manifold. The inlet manifolds and the plenum chambers are manufactured from carbon-fibre for weight reasons.

ELECTRONICS

For the R10 V12TDI in 2006, a new, dedicated, motorsport ECU – the MS14.x for diesel mode – was designed in co-operation with Bosch. Many details of the ECU were developed over the following years.

However, for use in the R18 e-tron quattro, a completely new ECU (MS24.x) had to be developed in order to be able to represent the hybrid and engine operation in a single control device. The software for the hybrid operation – as well as for the entire operating strategy – was developed, programmed and created independently by Audi. The software for this and for other in-house developed functions was written to a dedicated partition, separate from the basic engine functions, in the MS24.x ECU.



Side-by-side comparison of the engine bays of the R15 V10TDI (left) and the R18 V6TDI (right)

HOT SIDE INSIDE

With the ban of 'snorkel like' air intakes – ie air inlets protruding above bodywork parts – a central air intake was the only efficient solution for an LMP1 coupe. Two closed monocoque Le Mans Prototype racecars had previously been designed and built by companies within the VW group – the Audi R8C from 1999 and the Bentley prototypes between 2000 and 2003. The difficulties of achieving good airflow with low resistance for a twin turbo system installed on the side of the engine were known from the Bentley project. Therefore, in order to fully exploit the dynamic air pressure, great value was attached to achieving a very short, fully streamlined route for the intake air.

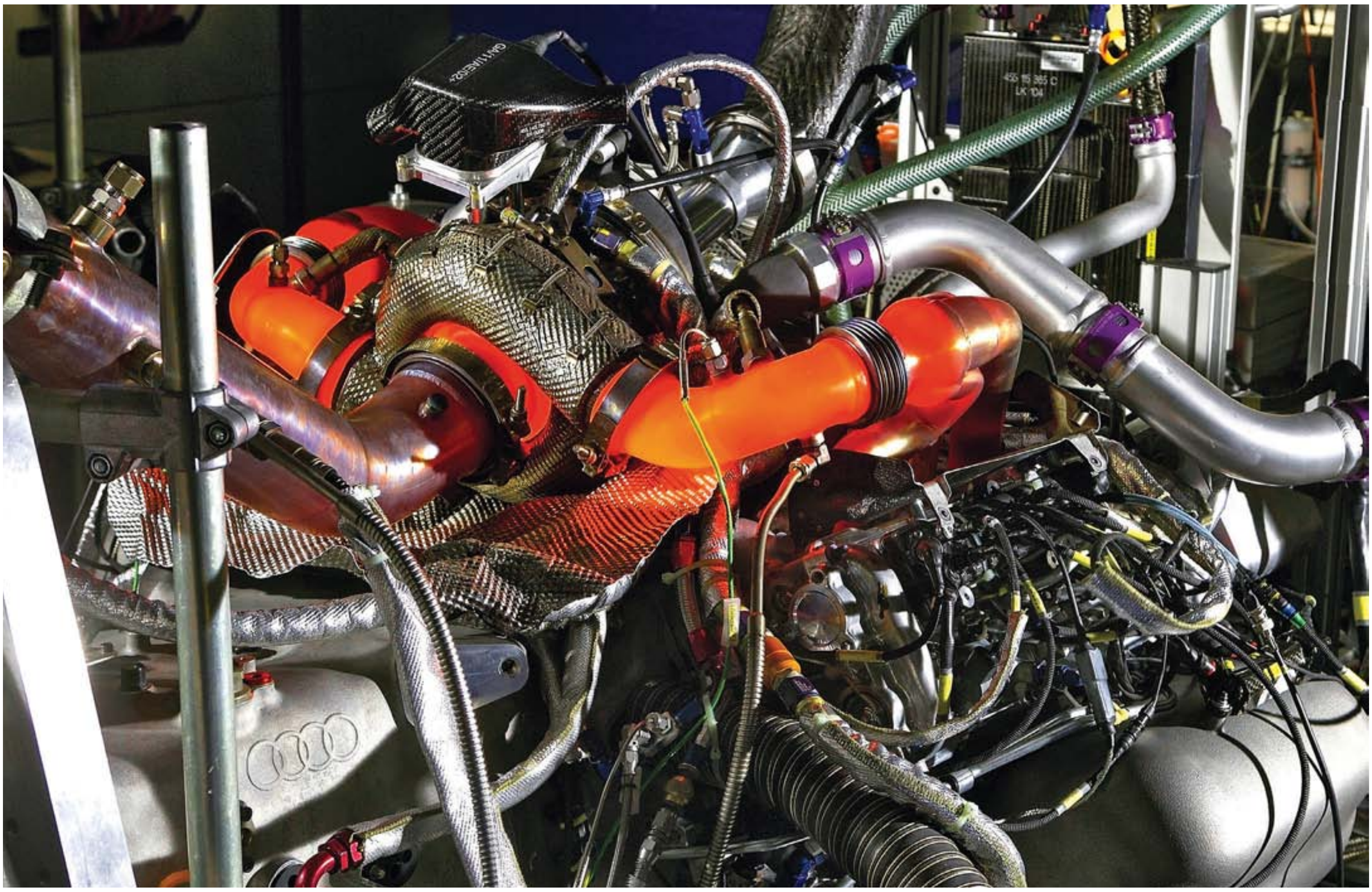
The following considerations were obvious to the Audi engineers: a central turbo layout, exhaust channels mounted in the engine's V, a wide V angle to make space for the turbocharger and a large cylinder bank angle.

Several concepts were developed for the inner V area – especially the exhaust system within the narrow constraints of the aerodynamic outer bodywork. A fundamental question was whether a single turbocharger can generate the same or even better initial response than a twin turbo system.

The calculations made by Honeywell Turbo Technologies indicated that the mono turbo with VTG was the superior concept. On top of this came the significantly lower air mass due to the reduced restrictor size, when compared to preceding engines, which made a mono turbocharger possible.

A consequence of 'hot side inside' is an externally mounted intake system with very short charge-air piping, which is advantageous for improved response characteristics. The unfiltered-

In order to fully exploit the dynamic air pressure, great value was attached to achieving a very short, fully streamlined route for the intake air



The Audi R18 engine under peak power condition, here shown without exhaust manifold insulation

air side of the engine induction system is made along the car's roof. The ducting incorporates a low pressure loss air filter and airflow to the restrictor is optimised. Exploiting the dynamic pressure at high vehicle speeds generates a marginal increase in mass flow rate. The air is compressed to the permitted boost pressure in the compressor and enters the intercooler at temperatures of up to 200degC. After cooling, it reaches the induction system through a short carbon-fibre connecting pipe.

Another aim of the externally mounted intake system was to achieve the lowest possible blockage of the radiator exhaust air. A result of the centrally mounted turbocharger was that a very simple and light exhaust system layout was possible with the DPF at the back of the car. This was changed for the 2013 season to allow the development of a 'blown diffuser' (see *RCE V22N6*).

To develop a diesel engine as a thoroughbred race engine is a great challenge from the very beginning. The task is further complicated by the necessity to integrate the engine perfectly in the very small overall package of a sports prototype. As with the R15, the engine and car were designed as a harmonic unit without weak points. To obtain the ideal suspension setup, all the car's stressed components must have an equally high stiffness, which is why the engine is mounted rigidly as a fully stressed member between the monocoque rear bulkhead and gearbox. The stiffness could be further increased by the use of very light backstays between the monocoque and gearbox casing. The installation of a turbo engine is significantly more complex than that of a normally aspirated engine due to the air ducting. The intercoolers and water coolers are located on both sides of the monocoque in close proximity to the engine – the result is low-loss flow for low duct volumes. The car side cooling-air ducts were optimised in the wind tunnel and ensure very efficient cooling of the charge air and water.

The R18 has been an imposing presence in sportscar racing since its introduction. While both the Peugeot 908 and Toyota TS030 have taken it on and beaten it in short distance races such as those that make up the bulk of the WEC, the R18 has so far proven unbeatable at Le Mans.

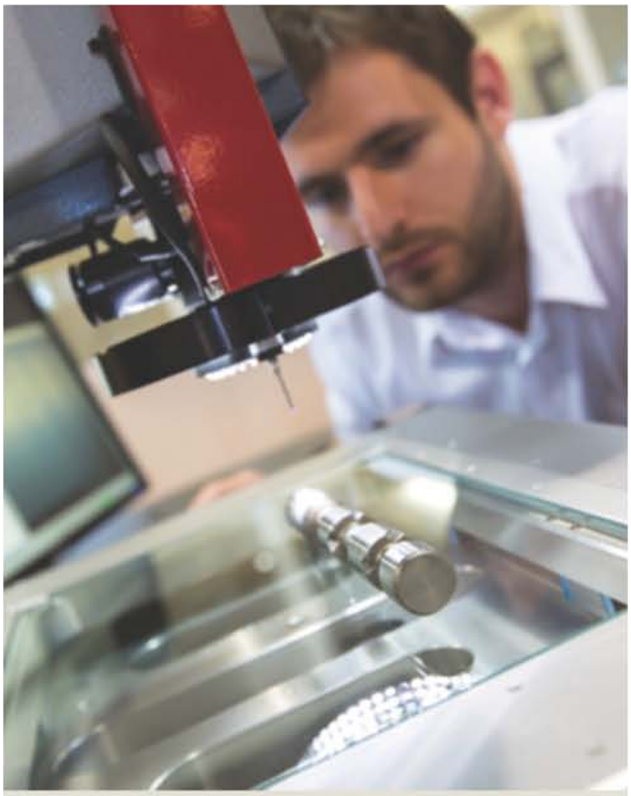
REVS AND LOADS

Because of the use of the mono turbocharger, it was necessary to increase the cylinder bank angle from the 90 degrees seen on the R10 and R15 to 120 degrees for the R18. This proved to be a very good compromise for the overall package concerning the centre of gravity position and sufficient stiffness for the fully-stressed engine as part of the whole car.

The number of main bearings reduced from six to four because of the number of cylinders. At the same time, the bore was increased by 3.5 per cent and, in addition, the maximum combustion pressure increased, which actually would have had to lead to higher bearing loads. However, by exploiting intelligent lightweight design for the entire crank mechanism, as well as clever mass distribution, it was possible to maintain the bearing loads level from the R15 in the R18.

With increasing revs, the maximum bearing loads reduce due to the ever-increasing inertia forces, while the mean bearing loads increase. The change of the cylinder bank angle, however, leads to an increase in bearing forces in the lateral direction. Particular effort was necessary from the design side to prevent sliding in the joint.

For lower revs, this effect is even more apparent due to the dominating gas forces, in the upper rev range the effect reduces because of the revolving inertia forces.



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Typical examples include the visual assessment of machined components, checking for burrs and poor surface finish, and checking brake and fuel lines for quality of welding and plating. Engine and drive train components are of particular interest and are dimensionally critical.

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Blue SKY thinking

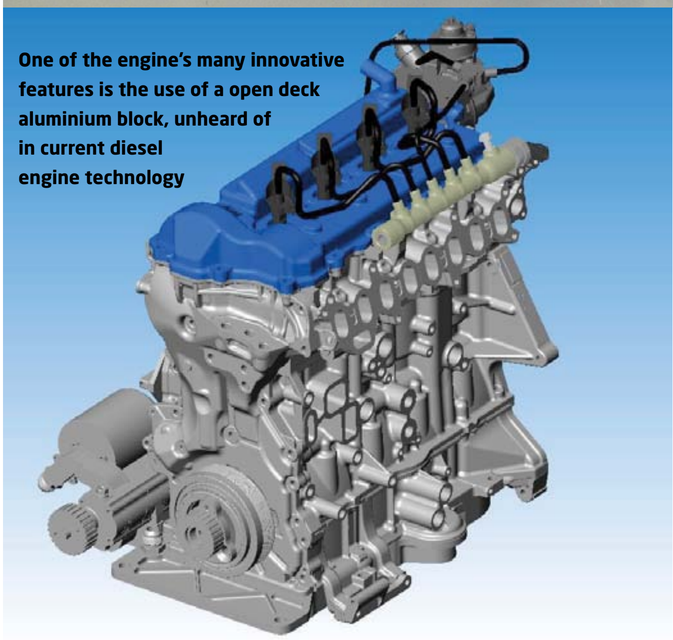
Mazda announce the first production-based, four cylinder, racing diesel engine

BY ALAN LIS

In the week leading up the 2012 Le Mans 24 Hours, Mazda Motorsport announced its intention to supply a new diesel race engine for LMP2 competitors in the 2013 event. A version of the same engine will also be raced in the new GX class of the US-based GrandAm series starting in 2013.

Both versions of the engine are based on Mazda's SKYACTIV-D power unit – a four-cylinder, 2.2-litre engine, which features a lower compression ratio than one would expect to find in a diesel engine. Dave Coleman, who has headed Mazda's R and D effort in Irvine, California on the SKYACTIV D production engine, explains: 'Lowering the compression ratio may seem counter intuitive but we've got it down to 14:1, which coincidentally is the same compression ratio used in the petrol version of the engine. The initial reason we did this was to achieve a cleaner combustion event. We were chasing an emissions target of raising the set standard without after-treatment of the exhaust. Lowering the compression ratio slows down combustion, and delays the start of combustion.'

With a low compression ratio of just 14:1, the 2.2-litre engine revs to 5200rpm and produces 450bhp and over 550lb.ft of torque in LMP2 racing spec



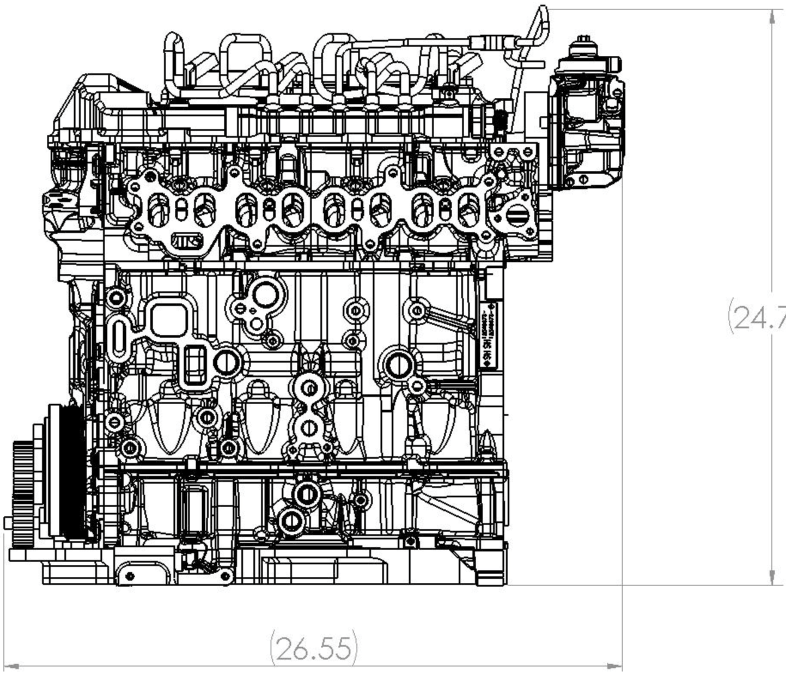
One of the engine's many innovative features is the use of a open deck aluminium block, unheard of in current diesel engine technology

COMBUSTION PROCESS

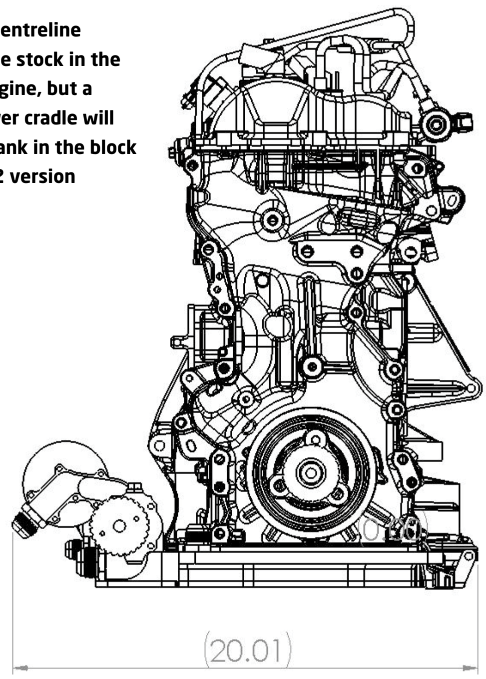
In a conventional diesel engine with a higher compression ratio, the combustion process starts as soon as the fuel is pouring into the combustion chamber. The result of this is a not very good mixture of oxygen and fuel molecules, which gives rise to a hot area around the edge of the fuel plume. As this area has plenty of oxygen and so burns very hot, it tends to result in a high level of NOx emissions. Alongside this, there is a rich concentration of fuel in the middle of the plume, which doesn't have enough oxygen to burn fully, so gives rise to soot.

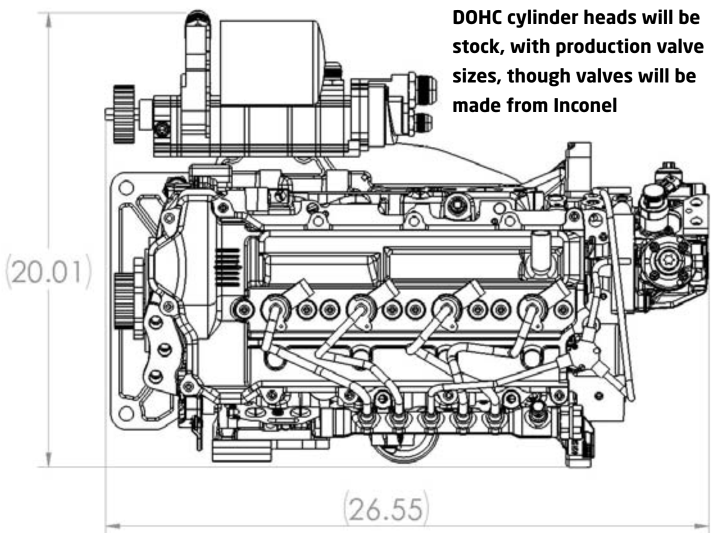
'If you try to pass the emissions standard with a high compression engine, you end up having to delay the injection of fuel until after the piston has reached top dead centre and, by doing that, you are throwing away some of your potential expansion ratio. Effectively, you are waiting until the conditions are slightly less hot, so it will take a little longer for the combustion event to begin. This allows more time for the fuel and air to mix, which results in a more homogeneous mixture.

'If you do that in a conventional diesel engine with a 16:1 compression ratio, the expansion ratio from when you actually start burning fuel to



Crankshaft centreline height will be stock in the GrandAm engine, but a bespoke lower cradle will lower the crank in the block for the LMP2 version





DOHC cylinder heads will be stock, with production valve sizes, though valves will be made from Inconel

the exhaust valve opening will only be around 14:1. If you just build the engine with a 14:1 compression ratio in the first place, the fuel can be injected at around TDC. The advantage of this is peak cylinder pressures are so much lower so we are able to make the cylinder block, cylinder heads, crankshaft and other parts much lighter. If you put the crank and rods of a SKYACTIV-D engine next to those of our previous diesel engine, the effect is almost comical. The old parts are so much larger and heavier by comparison.'

INTERNAL FRICTION

Coleman observes that the lightening of parts results in a snowball effect as the stresses reduce, and the end result is internal friction levels in a SKYACTIV-D engine comparable to those of a conventional petrol engine. 'That, in turn, allows us to rev the engine quite a bit higher that a regular diesel engine,' Coleman continues. 'In production form, the SKYACTIV-D will rev to 5200rpm. With the ability to run at that level we were able to build cylinder heads and a turbocharger system that would breathe well at those speeds. All of this makes it easier to take this stock block engine and turn it into a race engine. In fact, with the SKYACTIV-D technology we are a lot closer to a racing diesel engine, in terms of the way the engine is constructed.'

Another of the engine's big departures from a regular diesel engine is a die cast, open deck, aluminium block at the bottom end. 'That's unheard of in a conventional diesel engine, where you would typically have a closed deck, cast iron block – really heavy stuff,' says Coleman, with obvious delight. 'What we have is a block that looks like a petrol engine block in terms of construction because the forces involved are much closer, although its doesn't actually share any parts with the petrol version of the SKYACTIV engine.'

COMPOUND TURBOCHARGING

A further feature of the production engine, which is carried over to the race version is the layout of the turbochargers, though the racing application uses bespoke motorsport units.

'To achieve the driveability we were targeting for road racing, we have one turbo that does its thing in the lower rpm range and a higher pressure unit for the higher rev range,' explains Sylvain Tremblay, proprietor of SpeedSource Race Engineering, the Florida-based company that has been contracted by Mazda Motorsports to develop and build both the GrandAm GX and ACO LMP versions of the engine.

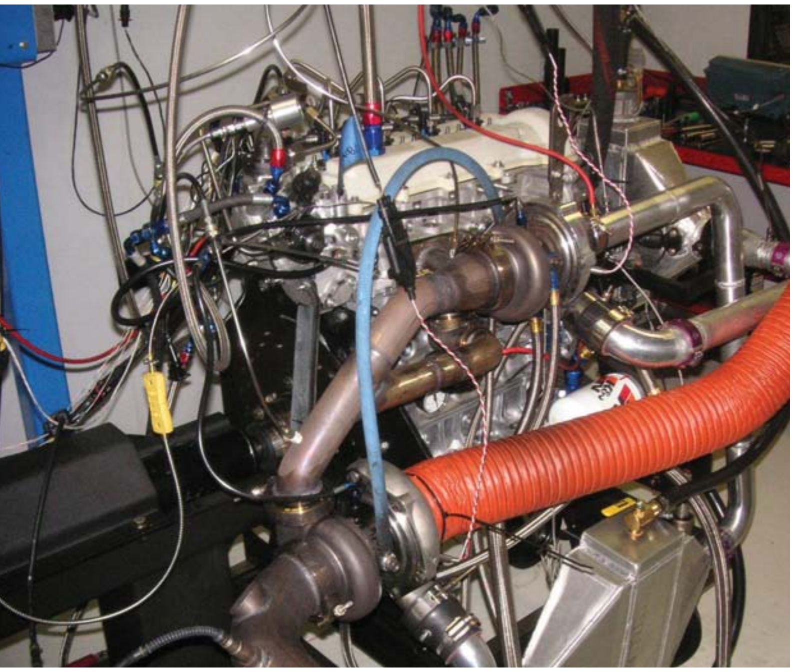
'The engineers at Mazda truly did make it easier for us. The design of the engine has allowed us to stretch and gain in areas of development that would have been impossible to do in the relatively short time period we had for this project. The fact we have a 5200rpm stock engine means we can trust many stock components up to 5000rpm without having to sweat it in the racing world. A lot of the efficiencies needed in a racing application are already done.'

"A lot of the efficiencies needed in a racing application have already been done"

While both the GX and LMP technical regulations call for race engines to be production-based, there are nevertheless differences in their specifications. 'The biggest ones will be in packaging,' says Tremblay. 'Crankshaft centreline height is a major consideration in an LMP car, while in a GT car the production crank centreline is sufficient. So on the LMP engine, the lower cradle of the engine will have to be a bespoke part. But many of the engine internals for both the GX and LMP applications will essentially be the same.

'We've done a lot of testing with production pieces. Currently, our plan is to have a bespoke crankshaft, simply for increased durability. We feel that while the production crank would be strong enough, it may not be cost effective because it would have to be replaced at the mandated 30-hour limit, whereas a purpose-made crankshaft would be more durable.

'Also, because of weight and



Though much of the production engine's components are up to the job in terms of strength, the race versions will use bespoke internals for improved durability

durability, the connecting rods and pistons will also be bespoke parts. For the bowl shape in the piston crown we will be using all the hard work that Mazda R and D has done in that area. The bowl shape is critical at the lower compression ratios we are using in order to have the best possible combustion.'

PRODUCTION PARTS

According to Tremblay, the DOHC cylinder heads of the race engines will be production parts, with the current plan being to keep the same valve sizes as OE, but change the material from which they are made to Inconel to withstand the higher pressures and temperatures of racing. The camshafts will be made from production blanks with SpeedSource's own specialised grinds on them. The OE valve springs have been replaced with aftermarket parts, but the rockers are off-the-shelf production pieces. There will also be carbon fibre valve covers to save weight.

The Nippon Denso fuel injection system of the production engine has been replaced with a Bosch Motorsport set up on the racing versions. 'In the racing applications we are still using the Piezo technology,' explains Tremblay, 'but with the Bosch MS15.1 ECU and Bosch Motorsport pump and injectors.

'The injectors we are currently using have eight holes but we are also experimenting with a 10-hole version. The Piezo technology essentially allows us to do pre- and post-injection of the fuel, and in all we can have as many as eight injection events in a single combustion cycle.

'To date, the lower compression ratio hasn't given us any problems in the racing applications. We thought that start up might be an issue but it's not. We can use glow plugs to start the engine and keep them on to reduce smoking. Our plan is to incorporate a diesel particulate filter, but we already have a very low smoke engine because of the low compression ratio."

"The bowl shape is critical at the lower compression ratios we are using"

At Le Mans, the SKYACTIV-D engines will run on the ACO's own spec GTL (gas-to-liquid) diesel fuel – LM 24 – while in the GX class the fuel is required to be commercially available. 'For the GX programme all of our initial testing has been done with US-grade diesel, which has a relatively low cetane number, and that has been challenging,' says Tremblay. 'With our partners we are looking at alternatives, including bio-diesel, but we can't use specially developed racing diesel. We will definitely use a fuel with a higher cetane number than the current pump fuel in the US, which is extremely low. European stock diesel is around 50-55 so it's relatively good grade fuel. American diesel historically has a low cetane number – around 40. That's not an issue at low revs, but one of the benefits of this engine is its ability to rev at a higher level and the flame front in a 40-cetane fuel is too slow. The cetane number in a diesel fuel is a determining factor for rpm.'

Despite the different fuel specs internal differences in the GX and LMP engines will be minimal. 'The biggest difference is in the spray pattern at higher revs and power levels,' explains Tremblay. 'As we look at the LMP application, which has a higher power requirement, we will need better fuel. The GrandAm GX application uses a lower power level for which standard pump fuel won't cut it, but it doesn't need to be as potent as the LMP fuel. The internals such as the piston bowl design will stay consistent for both applications. The injector pin count and angle may or may not change.'

Tremblay quotes peak power targets of around 450bhp for the LMP engine and 400bhp for the GX version, but says his preference is peak torque figures. These are above 550ft.lb in LMP form and 500ft.lb+ in GX form.

John Doonan, director of Mazda Motorsports, adds: 'The neat thing about the SKYACTIV-D race engine project was that the existing rules for GrandAm GX and ACO LMP2 allowed us to carry out parallel development. The power and torque levels we were targeting were similar. When GrandAm came to us with the GX concept it allowed us a new opportunity, but the cool thing was that we were already attempting to achieve power and performance targets at the higher level.'

Clearly, the lack of aftermarket parts for its racing application has been a significant challenge. 'Any new internal and external parts we have needed we've had to engineer, design and build in house,' says Tremblay. 'It's been a great help to work with Bosch and

Garrett, who already have extensive experience of diesel racing programmes, but the biggest single challenge has been that no one has yet built a production-based, four-cylinder, compound turbo, diesel race engine. We are breaking new ground and we've been climbing uphill throughout the programme so far.'

TECH SPEC

SKYACTIV-D

Displacement: 2191cc

Bore: 86mm

Stroke: 94.3mm

Estimated Weight: 325lb (148kg)

Horsepower: 420bhp / 336kW

Torque: 505ft.lb / 685Nm

Max engine speed: 5200rpm

Rotation: clockwise (from front)

Engine block: OEM aluminium

Camshaft : dual overhead, SpeedSource-developed

Valves: four valves per cylinder, SpeedSource-developed

Head: OEM Mazda, SpeedSource ported

Pistons: anodised aluminium alloy

Con rods: forged alloy steel

Crankshaft: alloy steel

ECU: Bosch Motorsport MS15.2

Intake manifold: SpeedSource developed

Exhaust manifold: OEM Mazda, integrated in head

Turbo and wastegate: Garrett Motorsport; air-to-air intercooler

Fuel injectors and pump: Bosch Motorsport

Fuel rail: OEM Mazda

Oiling: SpeedSource-developed

Cooling: SpeedSource-developed

Fuel: Shell LM24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Ford's other V8

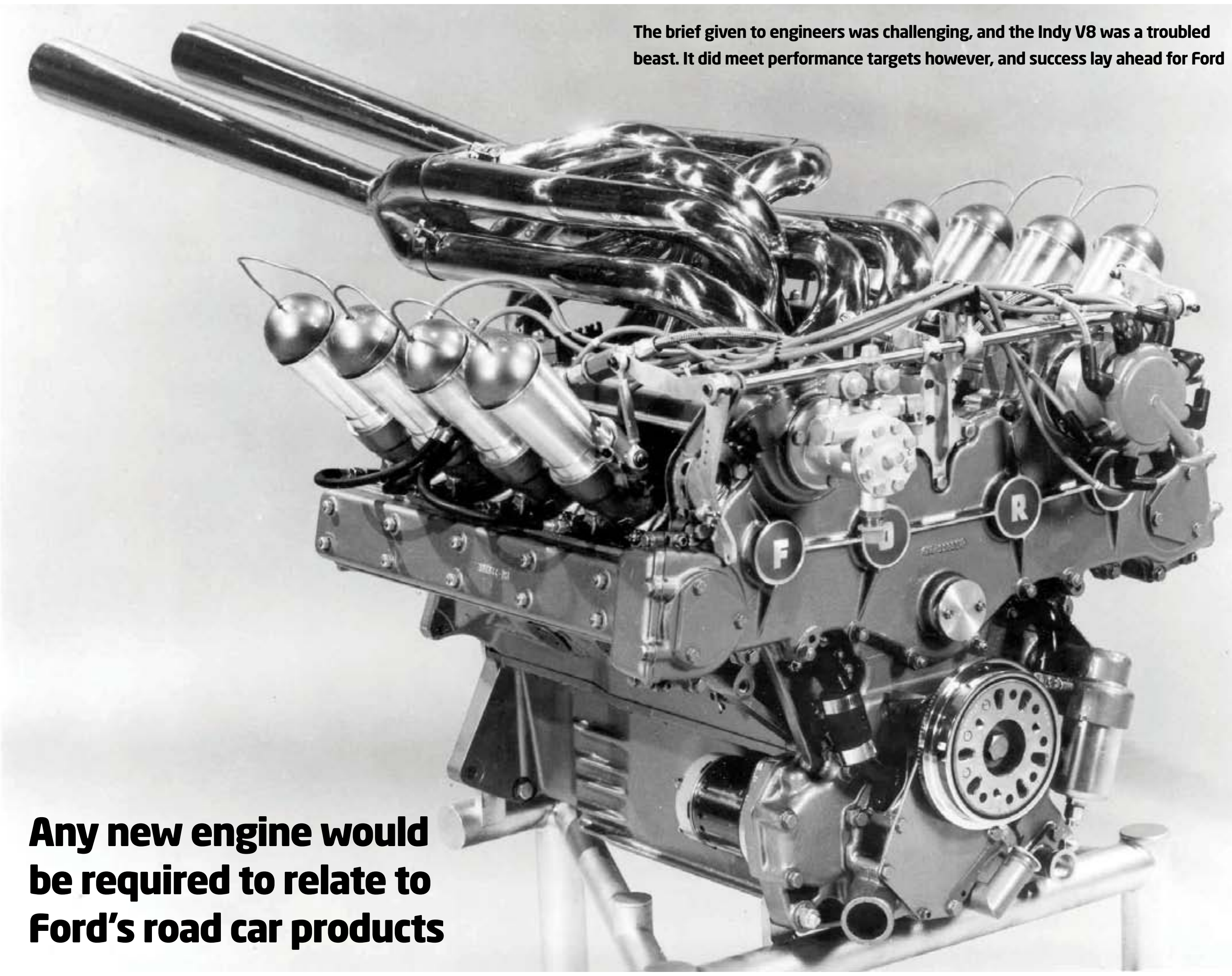
Ahead of the 1964 Indy 500, engineers had a gap to make up, which would call for a radical rethink under the hood...

BY LAWRENCE BUTCHER

Ask most people to name a twin cam Ford V8 built in the 1960s and they will say the DFV. But it's little remembered that the company's factory Indy engine came a few years earlier.

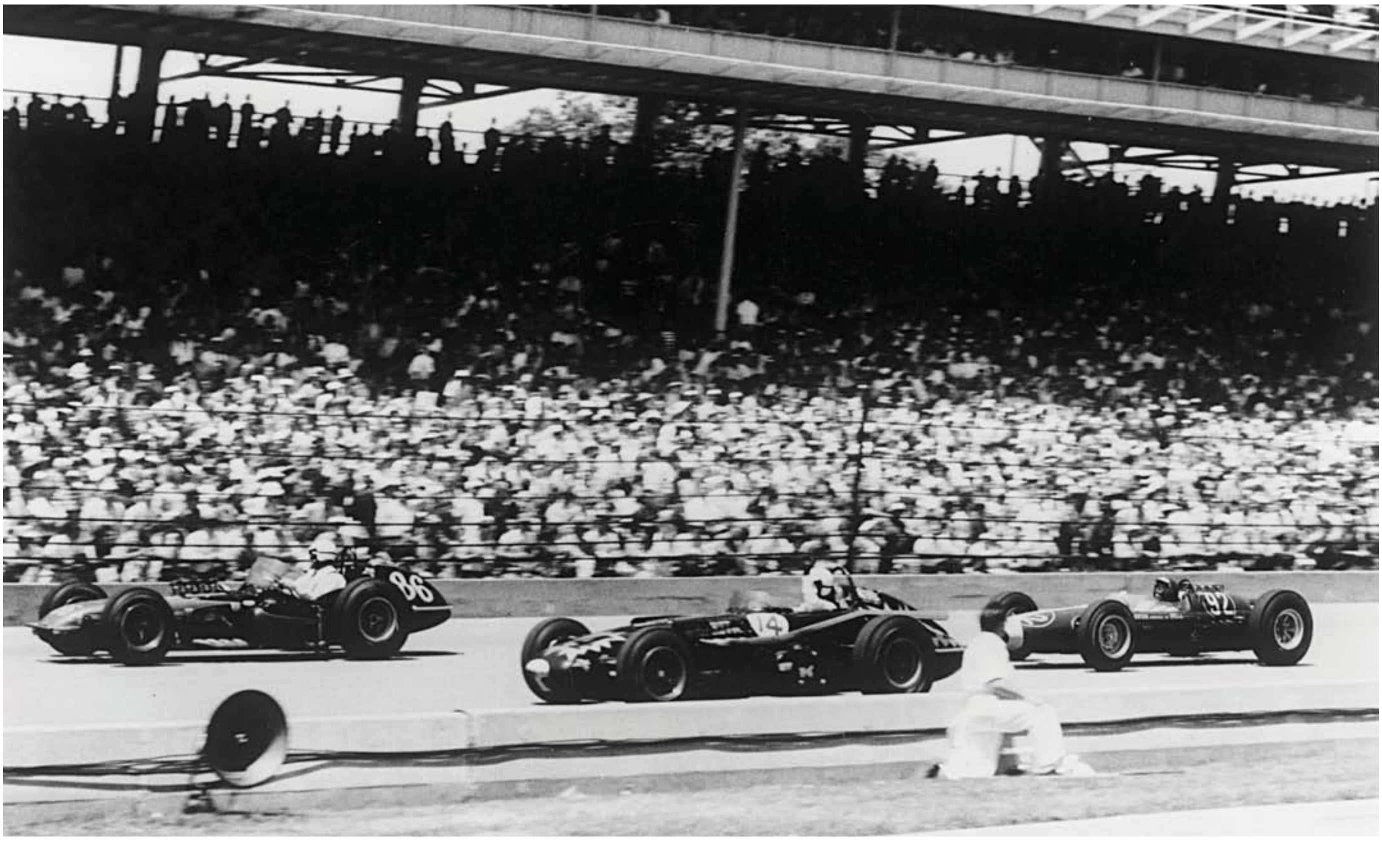
When one thinks of 1960s racing, the image that comes to mind is the garagiste operations such as Lotus and Cooper, with even Ferrari being far removed from what would today be considered a modern racing operation. However, when the Ford Motor Company decided to put its mind to building a new Indy engine, with it came the might of its R&D department. In 1963 a Ford-powered Lotus 29, driven by Jim Clark, came tantalisingly close to winning the Indianapolis 500, and was prevented from doing so only by the leading roadster of Parnelli Jones dropping oil on the track. The Lotus was running a development of Ford's Fairlane pushrod V8; drawing pump fuel through carburretors, it produced far less power than the competition's highly tuned Offys running on the more usual Indy brew of methanol. It was clear that the 375hp produced by the 255cu in V8 was not going to be competitive in 1964, regardless of the quality of chassis, so work began to create a new, twin cam unit based on the Fairlane block. This was not an acceptable situation for the Blue Oval, and the company embarked on a development program to take the venerable Fairlane engine to the next level. However; any new engine still had to relate to Ford's road car products – the fans had to be able to associate it with the motor under their hood. These performance and marketing requirements led to the team drawing up four key design criteria. Achieving these goals would be no small task and the engineers at Ford were presented with a challenging brief...

- Make the 1964 engine as competitive as possible in terms of horsepower at the minimum RPM.
- Keep total engine weight under 400lbs.
- Run on gasoline, not methanol, to maintain a stock car image.
- Retain carburretors or adopt an existing fuel injection system.



The brief given to engineers was challenging, and the Indy V8 was a troubled beast. It did meet performance targets however, and success lay ahead for Ford

Any new engine would be required to relate to Ford's road car products



The 1963 Indy 500 saw Ford power a Lotus 29. The engine produced 375bhp, woefully short of what was required for 1964 which saw huge development

The unit would be competing with engines from the legendary Offenhauser, and it was projected a power figure of 420-25hp would be required to keep up, an increase of 50hp over the 1963 engine's 375hp. Meanwhile, the weight could only increase by 40lbs over the 63's 360lbs.

To achieve this with a maximum engine capacity of 255 cui – the maximum permitted by the regulations – the engineers calculated that the engine must be capable of revving to 8000rpm. Though by modern standards, this doesn't seem particularly high, the manufacturing and material technology of the day made it a tall order to a pushrod V8. It was therefore decided very early on in the project that a double overhead camshaft arrangement would be called for, which was to become the primary design consideration. It is tricky to imagine in these days of incremental developments, stifled by regulation, that it would be possible to undertake such a monumental shift in design from one year to the next.

In1964, the days of 3D modelling were yet to be discovered, as were other useful computer aided design tools (though the Ford motor company did have significant computing resources even then). This meant that testing all had to be physical, so the Ford engineers embarked upon a programme to build a prototype engine. From this initial prototype the team could then determine which components were suitable for retention from the 1963 engine and, more importantly, validate the overhead camshaft system and ensure that the initial horsepower projections were actually met. Both dynamometer and vehicle testing of the first prototype confirmed that the aluminium cylinder block and the rotating components from the pushrod engine were up to handling the increased power output. It also showed that a pentroof cylinder head design would permit a peak of over 400hp at 8,000rpm, bang on target to compete against the Offys. The initial prototype also ran carburettors, 58mm Weber downdraught units, the same units as used on the pushrod engine the previous season. However, these were ultimately not deemed to be sufficient for the race version of the engine and were replaced with a Hilborn injection setup. This was a purely mechanical setup, but until 1964 it had only been used with methanol fuel, meaning that it needed to be modified to suit Ford's purposes. Beyond the basic mechanical modifications to accommodate the required flow rates, the injection system also saw extensive testing in the wind tunnel. These tests were undertaken with a running vehicle, to ensure that the system would not suffer from problems such as fuel vapour lock due to excessive temperatures. This is where the benefits of Ford's might really came to the fore, with the company's in-house testing facilities proving invaluable. Though originating as Hilborn equipment, the final system used on the Lotus 34 was extensively modified by Ford, not only to suit the fuel type, but also to improve the fuelling curves to provide smoother power delivery.

It was a monumental shift in design from one year to the next

Ford's engineering clout also appeared in the manufacturing practices used to construct the Indy motor. The combustion chamber shape devised by the engineers was impractical to machine using the equipment available, so a then cutting-edge technology was put to use: EDM, or Electrical Discharge Machining. At the time this technology was being investigated at Ford's Manufacturing Development Group and it proved ideal for the task at hand. The basic principle of the EDM method is simple: metal removal is achieved by an intermittent or pulsed high energy spark from a direct current source. The spark discharges from an electrode to the work piece in the presence of a dielectric solution which covers the piece. The metal is removed by the spark through melting and vaporisation of a minute volume of material at the point where the spark meets the dielectric/workpiece interface. Using this method, the engineers were able to produce the complex combustion chamber geometries far more

The 1965 Indianapolis 500 saw the Ford engine upgraded to run on methanol fuel for the first time, which produced more power and cooler engine temperatures, helping Jim Clark to win the event for Lotus having led 190 of the 200 laps

accurately than would be possible using traditional machining. Additionally, the process was quicker than milling, saving time on what was a very compressed development schedule.

One area of the engine's design that presented problems was the lubrication system. Initially, the design team carried over the existing dry sump system from the pushrod engine, consisting of single scavenge and pressure stage pumps, with the oil stored in a tank towards the front of the car. The first problem the designers ran into was providing sufficient oil to the cam lobes, which necessitated an increase in size for the pressure side of the pump. This, in turn, placed a greater demand on the scavenge stage, not only in terms of the volume of oil needed, but also as a consequence of the increased tendency for the oil to foam as it drained back from the camshafts.

To counter this, the scavenge stage was doubled in size while the pick-up pipe diameter was increased by 50 per cent. The result was a sufficient supply of oil to the bearings, in addition to adequate scavenging of the crank case.

MORE TROUBLES

Another problem the engine suffered from was excess oil being ejected from the breather system. The cause was identified as a combination of two issues: windage from the action of the crankshaft, combined with the large amount of throw-off from the reciprocating components caused by the large bearing clearances. It must be remembered that bearing and machining technology was not as advanced as it is today, and to ensure sufficient cooling and lubrication, race engines tended to run very generous clearances. To put this in perspective, modern race engines will run on multi-grade oils as thin as 0-40w, the Ford Indy twin cam ran on 50w mono-grade, after testing showed 30w accelerated wear to unacceptable levels. The oil system breather also needed to cope with the volume of air and gases being drawn from the sump by the scavenge pump. The problem of breathing was solved by simply increasing the diameter of the tank breather system to reduce the internal tank pressure. To increase the effectiveness of the system further, a second scavenge pump was subsequently added to the system, which also insured against failure of either pump. Overall, the changes made to the system sound very familiar to those one would undertake today in converting a road engine for race use.

Unfortunately for Ford, the 1964 Indianapolis 500 was not the success it was supposed to be. Lotus entered three Type 34s in the race, with Jim Clark taking pole and beating the existing lap speed record by 7mph, but come race time the cars ate their tyres and failed to finish. The engine, however, proved its worth and met its performance targets. For 1965, Lotus returned with the 38, a dedicated Indy car (the 34 was a modified F1 chassis), which it was hoped would prove much more durable. The chassis featured a revised monocoque of much stiffer and more substantial construction, and the engine was also more powerful. The biggest difference between the 64 and 65 engines was the decision by the team to switch to methanol fuel, which not only provided more power, but also allowed cooler running. While methanol engines need to run far richer than gasoline units to overcome the fuel's poor octane rating; however, its high heat of vaporisation results in considerable internal cooling of the engine. The result was a near 100hp increase in power with the evolution produce over 520hp at 8600rpm. With the new car, revised engine and the slickest pitstops on the grid courtesy of the legendary Wood Brothers pit crew – drafted in by Ford from NASCAR – history was made at the 1965 500. Clark led 190 of the 200 laps comfortably winning the race; from that point on no front engine car would ever win at the Brickyard again.

TECH SPEC

1964 Ford Indy V8 Specification

Type: 90-degree V8 DOHC

Bore: 3.76 in

Stroke: 2.87 in

Displacement: 255.3 cu in

Power output: 425bhp @ 8000rpm

Compression ratio: 12.5:1

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Start your engines

A holding pattern for engine development in IndyCar was planned for 2013. So, an ideal time for some mild tinkering...

BY MARSHALL PRUETT

IndyCar Series engine providers spent 2012 learning about their brand-new, 2.2-litre turbocharged V6 powerplants with an understanding that limited changes would be permitted during the off-season.

The progressive, year-by-year rules structure that came from the IndyCar Engine Committee (IEC) was a direct result from input by the series' three manufacturers – Chevrolet, Honda and Lotus. From those IEC meetings, the decision was made to treat 2013 as much like the second of a two-year development freeze as possible.

Chevy, with its Ilmor-built twin-turbo engine, dominated the first year of the new-look series with prodigious power and reliability, claiming 11 wins, the manufacturers' title and powering Andretti Autosport's Ryan Hunter-Reay to his first championship.

Honda, by stark contrast, won the IndyCar's crown jewel, the Indianapolis 500, with Chip Ganassi Racing and Dario Franchitti using its single-turbo powerplant, and three other events with Ganassi and Dale Coyne Racing, but suffered too many engine failures to accelerate its development program to offer sustained challenge against Chevy.

The general reckoning was that by the season finale on the 2-mile oval at Fontana, Ilmor and Honda Performance Development were equally matched on pace, but both manufacturers looked to the long six-month off-season to ignite robust development plans.

The greatest opportunity for advancement came with the allowance of a complete redesign on fuel systems. With Lotus having exited the series in December, Chevy and Honda were left to alter any aspect of the combined port- and direct-injected architecture found with both engines, as well as commissioning workflows to improve reliability and performance within the boundaries of homologation guidelines.

'When we were first sitting down and drafting the regulations, we originally weren't thinking much of an update for 2013,' said HPD technical director Roger Griffiths. 'But what we all agreed on was particularly in the area of direct injection – it was all pretty new for all of us. And

'We felt that it would probably be prudent to allow us to go back and have a second look and make sure we had made the right decisions a year earlier. So that's the background as to why there's an interim step there, rather than the major changes that are coming in 2014.'

Comprehensive changes await Chevy and Honda once the 2013 season concludes, with new cylinder heads and induction systems including plenums, piping and a change in the number of turbos used.

> **"We're taking advantage of the fact that anything the fuel touches is allowed to be changed"**

we felt that it would probably be a wise thing to allow us the opportunity to make a change on the fuel system because that area was very new. We didn't know quite how it was going to work and we wouldn't want to be stuck with carrying a bad decision over two years on the fuel system, because it was an area that was evolving so fast.

Honda can move to twin turbos if desired, while Chevy can reduce to a single BorgWarner unit, and new camshafts are permitted. For now, manufacturers have zeroed in on fuel systems as the primary target for innovation, and according to Chevy's IndyCar programme manager, the Bowtie felt confident in its 2012 system to carry over elements of its design.

'We certainly didn't throw it away and start over,' said Chevy's IndyCar manager Chris Berube. 'We had decent performance, but we were learning quite a bit throughout the season last year. Now we're taking advantage of the fact that anything the fuel touches was allowed to be changed.'

Griffiths and his team at HPD spent 2012 monitoring high-pressure DI developments that will soon grace Formula 1's turbocharged engines. Like Chevy, HPD opted to retain some of its existing fuel system while searching for new advancements to incorporate. 'As you talk to the various fuel systems suppliers, they're coming up with new ideas,' he said. 'One of the big things that's happening is the F1 regulations. They've committed to a V6 turbo direct-injection engine operating at a 500 bar limit, and we're at a 300 bar limit. What it means is that they now have much more experience operating at these higher pressures. When we first went to manufacturers a couple of years ago, we mentioned 300 bar – that's way higher than

where we are today on road cars. And particularly with the ethanol fuel and the demands of the flow rates required to get the performance we're looking for, we were in uncharted territory.

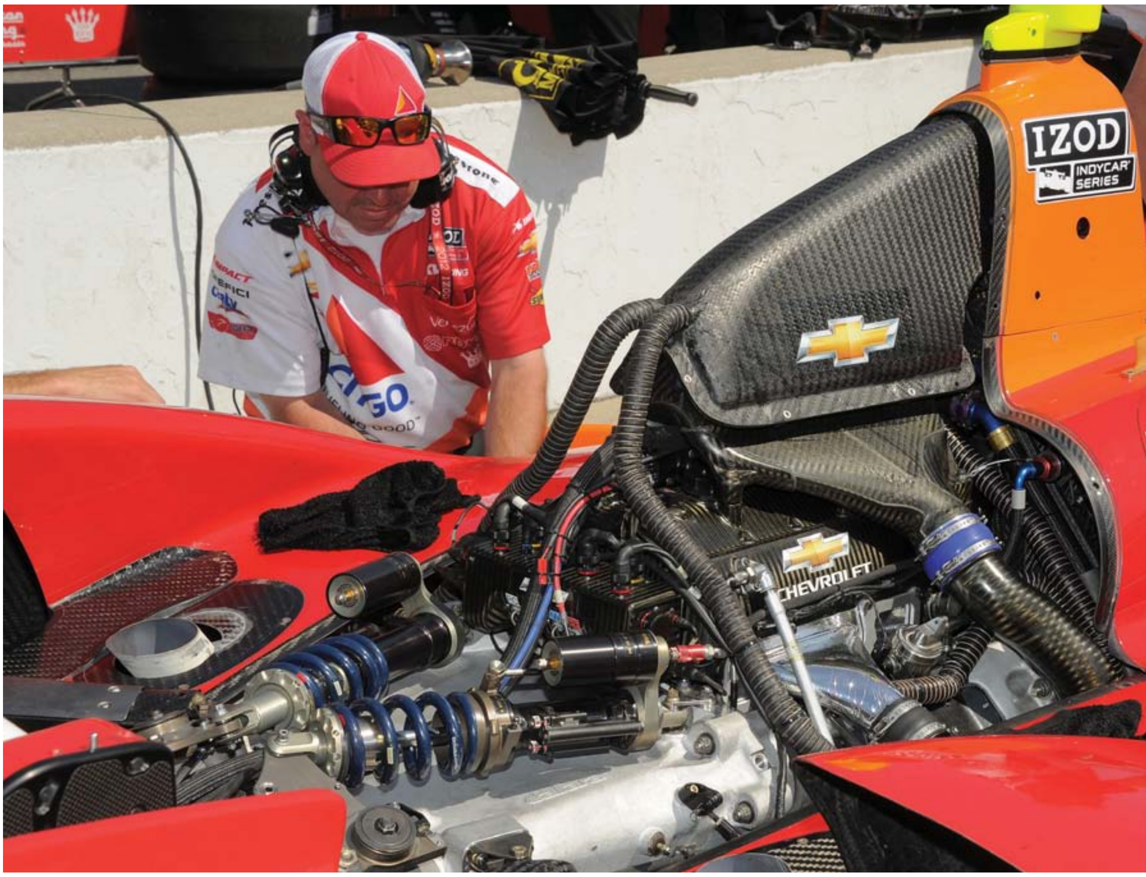
'It didn't matter whether you were talking to Bosch or Magneti Marelli, or Hitachi, or to any of these people – they were all coming back with the same kind of comment: "this is very new for us. We've got some stuff we're looking at for Formula 1, but it's pretty early." We've all had the opportunity of a year's worth of the development. Now we can go back and see what they've learned in the past year and see if that is applicable to what we're doing.'

Working with Hitachi, Chevy took the opportunity to move away from having its injectors working at different pressures. 'We've gone from low-pressure to high-pressure port injection for 2013 – that was a big change that we made,' said Berube.

'Now we are running at a DI pressure level, so the feed is consistent with the DI injectors and the port injectors now,' added GM Racing powertrains and advanced projects manager Russ O'Blenes. 'We're running off the same pump and fuel system.'

One of the most important decisions Ilmor and HPD had to decide upon during their respective fuel system re-homologations was how much further to skew towards using DI. With the rules limiting the use of a single port injector and a single DI injector per cylinder, plus a maximum of 300 bar to flow the spec E85 fuel, both marques struck a safe balance between achieving outright performance through port injection and fuel efficiency through DI in 2012.

The manufacturers would not be drawn on the percentage shift from port to DI for 2013, but both conceded a move was made. However, the ratio of port vs DI fuelling will continue to differ from track to track. 'We look all the time what the best combination of the two is,' explained Griffiths. 'Depending on the particular speed range that you're running on the engine and that particular demand that you've got on the engine, you'll make adjustments to the percentage that you use from one or the other.



For the 2013 season, Chevrolet have moved over from low-pressure to high-pressure port injection

'In certain areas you can get good driveability by having more of one than the other, and then in other areas you're chasing performance. So it's something we focus on greatly. I would say that each of the specifications of engines that we've brought to the racetrack have had a slightly different balance between the percentages of direct injection or the port injection. So it's not something where we said we need 60 per cent of this and 40 per cent of that and never will we change. It's something we look at continuously.'

F1-grade technology, as Griffiths notes, comes with F1-level costs. And with a restrictive price structure for IndyCar engine leases and mileage – $695,000 for five engines lasting 2000 miles apiece between rebuilds – a financial governor of sorts limited how aggressive he could be with 2013 DI developments.

'I think we made some sensible decisions,' Griffiths said. 'You also have to be mindful of how much money you're spending because the lease price still comes back to bite you. As soon as you start talking to people about Formula 1 components, you have Formula 1 prices and then you look at it and think: is it really the right place to be putting this type of fuel injector in or this type of fuel pump? The cost of it will make it more expensive than everything else that you've just looked at.'

ALWAYS OPEN

The IndyCar Series leaves the high consumption engine internals open for constant development, with valves, valve springs, retainers, spring seats, pistons, rings, wrist pins, circlips and bearing shells free for manufacturers to explore. Externally, wastegates are also free, and coatings are also open for revision at any time.

'We probably had every single coating manufacturer on the planet contact us with the latest and greatest in technology that they had,' laughed Griffiths. 'I think they must've seen that line item in the rules and everybody came out of the woodwork with some kind of spray-on coating or some cryogenic treatment. We obviously looked at them and then made a decision as to whether or not it was a technology that we wanted to apply.

'You have to be very, very cautious when you look at some of these things. Some of them actually work very well and others are, well, it's a bit of black magic.'

Ilmor chief engineer Steve O'Connor says the firm found more value in tuning its current wastegates through calibration developments than sourcing all-new hardware. 'The wastegate unit is not a major development item for us,' he remarked. 'We are always working on trying to ensure we run maximum boost without over-boosting the engine and suffer a (ECU controlled) boost penalty which will cost us time and track position. The wastegate and engine calibrations are both primary inputs for this. I would say the engine calibration is at least as important as the wastegate in this regard and it would be easy to get

"When you start talking to people about Formula 1 components, you have Formula 1 prices"

IndyCar is taking advantage of the progress made by fuel companies seeking 500 bar pressure for F1 to increase DI pressure to 300 bar in 2013

this wrong, so this is something we're continually developing and trying to avoid happening.'

It's also safe to assume that in the quest for additional performance, every permissible development item was evaluated.

'As far as everything else, the open areas of development, – whether it's pistons or valves – obviously we're looking all the time for what we can we be gaining,' said Griffiths. 'Is it friction reduction or is it better combustion, for example. Those kinds of areas are the bread-and-butter of our engine development.'

Chevy confirmed it produced a new specification of exhaust headers to start the 2013 season, and also revised aspects of its engine wiring loom to address some of the reliability issues of 2012.

Honda used header bag enclosures with its exhausts in 2012, citing a slight improvement in internal airflow, while Chevy did not. Berube added: 'We looked at that, but it's not the current path we're choosing to go down.'

A number of early engine failures were traced to control issues with the spec McLaren ECU, while others fell into the category of parts failures and even fuel-related issues, mostly fuel line and/or fuel injector fires. The reasons varied from straight failures to crash damage to teams/manufacturers intentionally swapping engines before the 1850-mile usage minimum – to prevent a possible high-mileage failure or to gain access to the most recent engine specification. The end result was 27 Chevys being changed early and 36 Hondas. Lotus, which ran with a single entry for two-thirds of the season, had 15.

Tackling the general topic of reliability was a priority for Chevy and Honda, but those durability initiatives were also dealt a wildcard with the fast-paced 2013 engine developments in mind. Between the revised fuel systems and engine internals, solving the issues that 2012 brought is only part of the challenge.

'We used the GM transient dynos very heavily and it's really your only outlet,' said Berube, referring to the heavy restrictions on track testing. 'Chevy had a decent advantage there. I can only assume how they react to problems and I'm going to assume it's on a very high level, but I'm very impressed with the way our team identified a problem and came up with a fix and implemented the fix to kill issues as soon as they came up. I didn't kill everything. And we had some problems that lingered.'

"We're always working on trying to ensure we run maximum boost without suffering a penalty"

IN THE LOOP

GM's O'Blenes, who leads the IndyCar dyno testing, described the cyclical nature of developing their engines without the luxury of unlimited track days. 'From my side, the interesting thing with the whole deal is that it's such a tight tie-in,' he said. 'Any time there's a component change, it drives calibration and software development, which then drives a revalidation. It's just like anything that's in that whole development loop where you do traditional dyno type power pulls, power testing kind of stuff on components and then a base calibration is developed for those components so that you can redo the validation side of it. Then in the background you're working on the transient side to develop your at-track driveability. Making sure that any system changes close that loop up.

'So you really have both wheels going at the same time because you're running durability on the components, and also you're also taking those components on the transient side to work on drivability and that sort of thing, so that when you go to the test you're able to spend time working on the car, rather than working on all the nuances of the drivability.'

HPD has also kept its dynos running steadily in search of greater reliability, but like Chevy, there are limits to the process. 'When we looked back on our season, it was the reliability of the engine that let us down more than anything,' said Griffiths. 'Is that something where you could say, OK, our transient dynos are going to be glowing red, running 24 hours a day throughout winter

as we try and look for everything and wear these things out to absolutely verify everything we want to verify to improve and increase our reliability? It sounds good, but it's not reasonable. But we've made a huge effort towards fixing it.'

Both manufacturers offered an estimated three to four per cent increase in power for the 2013-spec engines, which could mean as much as 50-70hp more, depending on the circuit and boost levels. No major issues were experienced prior to the season opener at St Pete in March, but reliability will continue to be a source of intrigue as more power is found.

McLaren's TAG-400i engine controller received frequent software upgrades throughout the 2012 season as engine manufacturers provided the firm with useful feedback and suggestions for improvements. Once Ilmor and HPD found a state of trust and comfort with it, the calibration race intensified.

'For calibrations, we're not changing McLaren's code and we're spending lots and lots of hours on dynos working on driveability, working on shift quality,' said Berube. 'Those types of things that can result in loss of time on the track.'

Honda played it safe with the 400is prior to the 2012 Indy 500, and along with other internal engine developments, unveiled a major leap forward with fuel mileage and boost control through the ECU that powered Franchitti and teammate Scott Dixon to a 1-2 finish at the Speedway. Now HPD and Ilmor are working to maximise the electronic updates sent through by McLaren.

'McLaren are also introducing new features and we had a fairly big revision to the way the knock control strategy works late on in the season,' said Griffiths. 'I think both parties identified some issues with the way the original strategy was working. We both pushed pretty hard to get McLaren to re-write the software, and we now have a much clearer understanding of what's going on within the engine. Whereas before we were fairly sure about what was going on, now it's something we feel a lot more confident in using.'

Honda won the Indianapolis 500 in 2012, but following a string of engine failures, there's been an increased focus on reliability for 2013

In addition to knock sensing capabilities, McLaren has implemented a few other updates and functionalities for 2013 according to IndyCar director of engine development Trevor Knowles. 'The major change is the new Push-to-Pass where the driver has a set number of pushes, each of which lasts for a set time,' said Knowles. 'There have been some minor changes to improve the action of the rev limiter and transient throttle response.'

The pace of development differed for Chevy and Honda last year due to the rate of problems encountered by both manufacturers. Honda, as noted, was a lightning rod for engine failures, and those breakages started once pre-season testing began in January of 2012. Chevy also encountered engine failures, but at a lower frequency, which allowed Ilmor to work through its planned list of updates and upgrades with limited interruption.

For Honda, the setbacks derailed many of its development plans through the first four rounds, leaving HPD a number of carry-over items to explore during the off-season.

'We had a lot of good ideas queued up and ready to go, but you were never able to get to them,' said Griffiths. 'And then you make the decision to hold fire and save things for 2013. It's a strategic decision. You have to say, OK, at some point you need to fix the real development focus to the next engine, rather than the current one. It's hard. You've got to keep pushing as hard as you can for the race that you've got the coming weekend, but you've also got to think, well, if I go flat-out all the way to the end, you're going to run out of time with your 2013 engine. You're not going to be able to do the things you want.'

PARALLEL PLANNING

'You've got to almost have this parallel path of one group of people working on the current engine and another group of people working on the future engine,' continued Griffiths. 'And sometimes when you're having problems with your current engine you have to pull people off your future development. so it kind of throws you off a bit. What we were able to do as soon as we got to the end of Fontana was say, OK, now it's full steam ahead for 2013 for everybody. That's how it's worked out.'

It's far from sexy and the average fan doesn't care about it, but with a year of combing through each budgetary line item, Chevy and Honda also spent the winter looking to curb excess spending wherever possible.

"Sometimes when you're having problems, you have to pull people off your future development"

With every engine lease requiring a significant subsidy, reducing fixed costs and operating expenses would allow for more time and money to be poured into development.

'At the end of the day, there is only so much money that we can spend on this project,' added Griffiths. 'And when you are effectively subsidising each of the leases to the tune of half a million dollars or something like that, that comes out of your bottom line.

'There's two aspects to it: the physical cost and the materials cost. How can we produce a component with the same functionality and the same quality but make it cheaper? And secondly, it's the operational cost. Can we make a cylinder head last two rebuilds? Can we last three rebuilds? Can we reuse a set of connecting rods? Can we reuse a flywheel? If our rebuild costs $100,000 one year, can you get down to $80k? $70k? Can we take five hours out of building an engine? All those things that we look at and say: how do we reduce the rebuild cost of the engine so you're not throwing away parts or time?'

Berube seemed to indicate its rival might have taken a deeper dive into the balance sheets.

'I guess I would first to admit to being in that same subsidy boat,' he said. 'First and foremost, our priority's on winning races so where we can – where we're inefficient with money – certainly we take it out, but we're not in a thrifting mode on the engine. Where it makes sense, will it look wasteful? Sure, but nothing dramatic.'

Chevy's primary job is to maintain its form, while Honda is tasked with catching and passing the reigning champions. Testing leading up to St Pete offered a glimpse of the significant progress made by Griffiths and Co., but with the rapid response times from both manufacturers, the 19-round championship will likely be a repeat of the back-and-forth battles seen in 2012.

Global forming

Toyota's new 1.6 litre, four cylinder engine could be key to the Japanese firm's return to the World Rally Championship

BY SAM COLLINS

Almost as soon as Toyota quit Formula 1 at the end of the 2009 season, rumours linked the Japanese marque to a return to the World Rally Championship. These rumours intensified when it was revealed that Toyota's European motorsport engineering consultancy, TMG based in Cologne, Germany had started work on an all-new engine suitable for the series.

The turbocharged 1.6-litre inline four was built to the so called FIA Appendix, or Global Race Engine, rulebook making it suitable for a number of applications including the the WRC and WTCC, but until now TMG has never admitted that it is working on a WRC programme.

'It is a rally engine,' says Rob Leupen, TMG's director of business operations. 'We are developing it for the WRC but we would like to see it used in other series like WTCC but I don't think that will happen soon. It is a TMG project to investigate a return to the WRC, but we are not sure which car we will use. Right now we are building a WRC prototype which we will use to test the engine next year. After that we will discuss with Toyota the possibility of a return to the WRC. We know that there are some new models coming and we are looking to 2016 or 2017. But what we are doing now will not be homologated.'

Work started on the new engine in 2010 and it ran for the first time in early 2012. A team of engineers headed by Norio Aoki, Global Racing's engine general manager, had to decide on the engine's source. The rules allow manufacturers to use a production block as a basis, or to create a bespoke design, and there are subtle differences in the regulations for each.

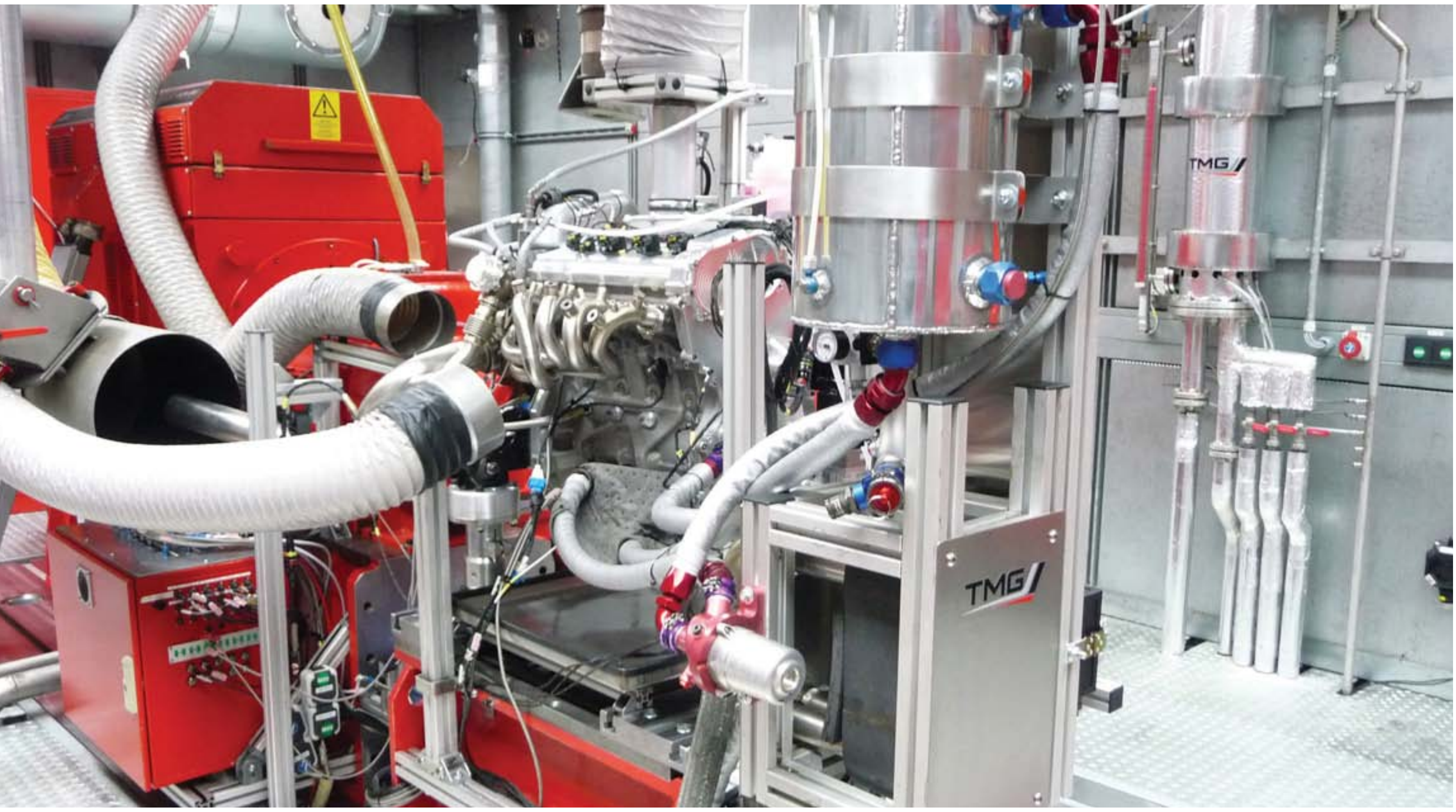
Those using production-based engines have a different main bearing size, which on paper allows for more power and less friction, for example. But most manufacturers, including TMG, have opted to develop the bespoke engine instead, as overall it lets them design things to be exactly as they want them.

'We looked at several engines in the Toyota lineup but decided to develop it from scratch,' says Aoki. 'It's nice to be able to develop a completely new engine, but it took some time to build up the team as we needed some new skills. Going to a four cylinder was a new world for us, as was direct injection.'

Because of the Appendix engine's roots in the GRE concept, many of the dimensions are not particularly written for a rally engine. Initially the GRE rules were intended to be used in 600bhp Formula 1 trim, which means that there are some odd details in the regulations, such as the 12kg crankshaft weight which is not ideal for a 300bhp WRC unit.

Despite the lack of references in-house, the TMG engineers

TMG opted against developing a mono cylinder version of the engine for testing, citing time and practicality as reasons for the four-cylinder route



The new engine, running on an AVL dyno. The turbocharged, direct injection 1.6-litre inline four was developed from scratch by TMG

decided against developing a mono cylinder version of the engine due to both time and budgetary contraints. 'We just went straight for the four cylinder,' Aoki says. 'With a normally aspirated engine, we would have gone to the mono cylinder to understand the combustion, but with a turbo engine we would need to simulate some of the back pressure, and this itself is a developmental step.'

TMG has a comprehensive engine development facility with a multitude of dyno cells and test rigs. In 2009 almost all of these were setup to run the big high revving normally 2.4-litre V8s and 3-litre V10s found in F1, but when the Japanese marque left that category TMG decided to increase its capabilities and now has a range of dynos suitable for smaller, forced induction engines such as the GRE and the forthcoming GT500/Super Formula NRE engines.

One major area of the still ongoing development of the engine is the injector shape and location. 'With this we do a lot of simulation and optimisation on the nozzle shape and spray pattern, but we work with a supplier who also suggested things,' says Aoki. 'There are two ways to use the injectors, either from the top or the side, and that was something to measure. We use what we have here in the best way and also collaborated with a university for the research, and the injector supplier also fed back to us.

The Yaris-R concept car, which could form the basis of the next generation Toyota World Rally Car, will make its public debut at the Frankfurt motorshow

'We have not decided on the nozzle shape, it's possible that we will use an off-the-shelf part – that's the cheapest route but it may not be the best. With more budget you would test limitless shapes and patterns but we have to make this engine commercially.'

One choice that TMG was not troubled by in the engine's development was the selection of a turbocharger. All cars in the WRC have to use an off-the-shelf unit that they cannot adapt or touch. Despite the limitation, TMG is still developing the engine as it does not have to homologate it before it goes into competition.

'With road car engines you get to a certain point and they are done, but you never really finish racing engines,' continues Aoki. 'As long as you have the opportunity to change things, even with F1 engines which were homologated, people were tweaking things due to reliability problems. With this engine we have lots of freedom as we are not racing yet.

'If we run without a restrictor, different turbo, camshaft and timing then there is more power, but there is more potential. I think there is a big spread between the GRE engines, and we fully expect to be at the top of that spread.'

The first official engine installation of the TMG GRE is in fact not a competition car at all. It will make its public debut at the 2013 Frankfurt motorshow in the front of the new Toyota Yaris-R concept car, which according to Toyota is 'a highly focused machine, designed to deliver the maximum driving pleasure.' It is believed that it may form the basis of the next generation Toyota World Rally Car.

"I think there is a big spread between the different GRE engines – and we fully expect to be at the top of that spread"

POSITIVE RACE FEEDBACK FOR HYDRAFLOW CONNECTOR

The challenge for Hydraflow's new clamshell connector, the 14J21, was to see how it performed in race conditions, following successful extensive research and development testing.

That it came through a gruelling first half of the BTCC season in a variety of under bonnet applications with the Motorbase Performance Airwaves squad should not have come as a surprise - but it has been the simplicity and safety of operation that has made an impression on the Motorbase engineers.

'To start off with, we were quite happy to work with the 14J21, as it seemed to have the attributes of a step change in this type of product,' says Oliver Collins, the Motorbase Performance team manager. 'But, it soon became apparent that the better engineering and ease of operation have definitely made life easier for our guys. The integral safety strap is an added bonus, as it is a visible check that the unit is securely closed.'

Specialty Fasteners, who distribute the Hydraflow 14J21, argue that there is a trend away from adapters and hoses towards CNC machined tubes that can be joined or dismantled swiftly, creating cleaner installations as a side benefit.

The 14J21 is particularly suitable for use in turbocharger installations, as they are much less likely to be affected by the variations in temperature associated with this type of application.

Finished in striking red, the 14J21 series is offered in all tube diameters from 0.5" through to 4" with butt weld aluminium flanges and seals offered to complete the package. CAD models are also available upon request from the worldwide distributors, Specialty Fasteners and Components.

Contact Graham Leo on +44 (0)1803 868677